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(54) **CLOSED LOOP VELOCITY CONTROL TECHNIQUES BASED ON SENSED TISSUE PARAMETERS FOR ROBOTIC SURGICAL INSTRUMENT**

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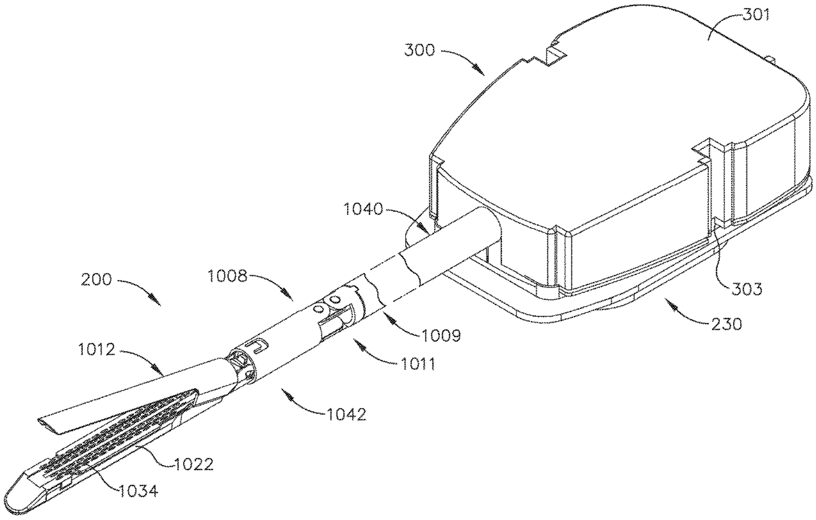
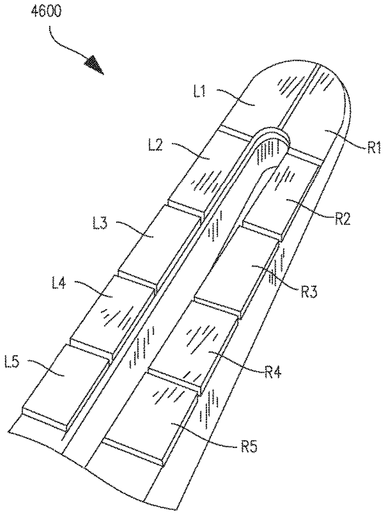
(57) **ABSTRACT**

The present disclosure provides a robotic surgical system that includes a control circuit configured to detect a condition at an end effector during a closure phase. The control circuit detects a condition at an end effector during a closure phase. The control sets command velocity of a motor coupled to a displacement member coupled to the end effector based on the detected condition at the end effector during the closure phase. The control circuit fires the displacement member at the set command velocity and detects a condition at the end effector during a firing phase. The control circuit sets command velocity of the motor based on the condition detected at the end effector during the firing phase.

10 Claims, 29 Drawing Sheets





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See application file for complete search history.

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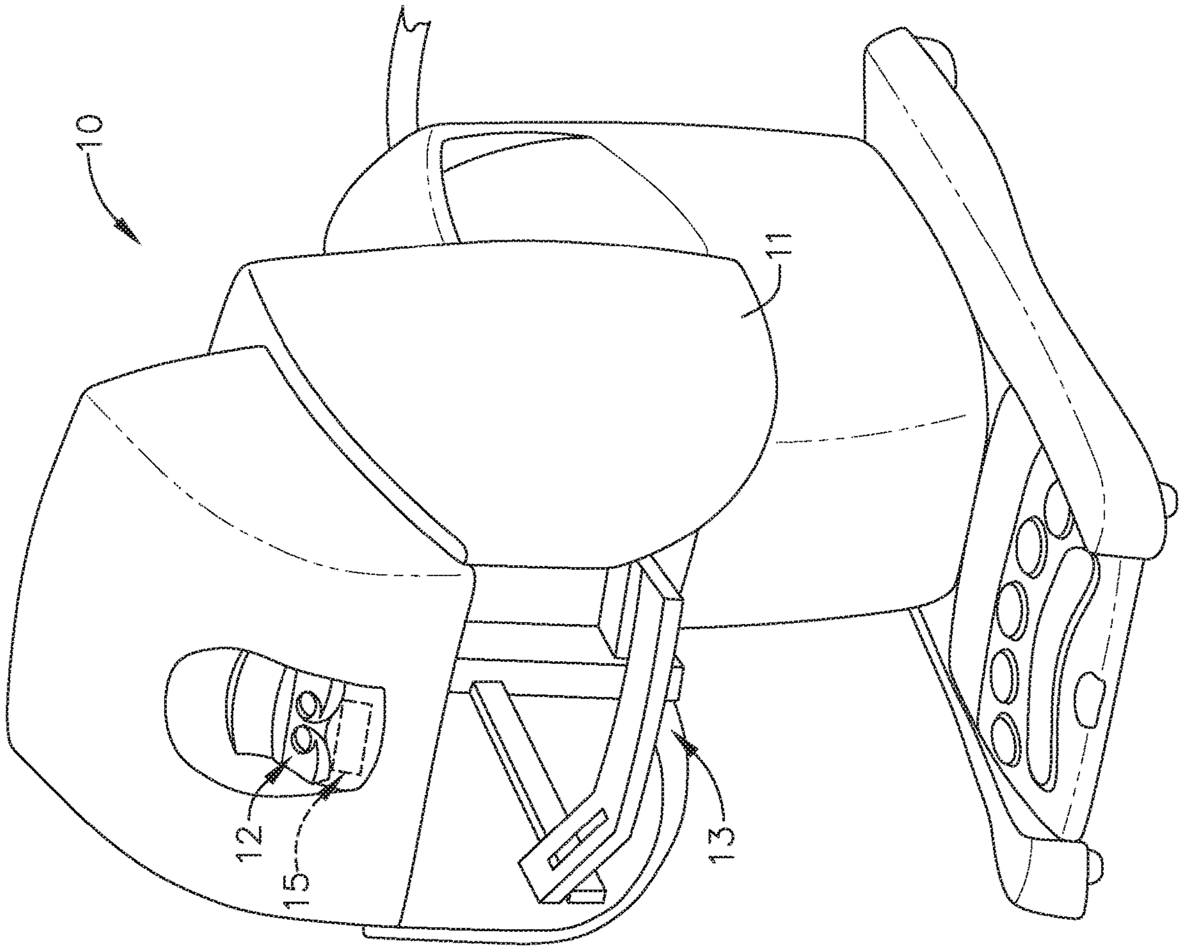

FIG. 1

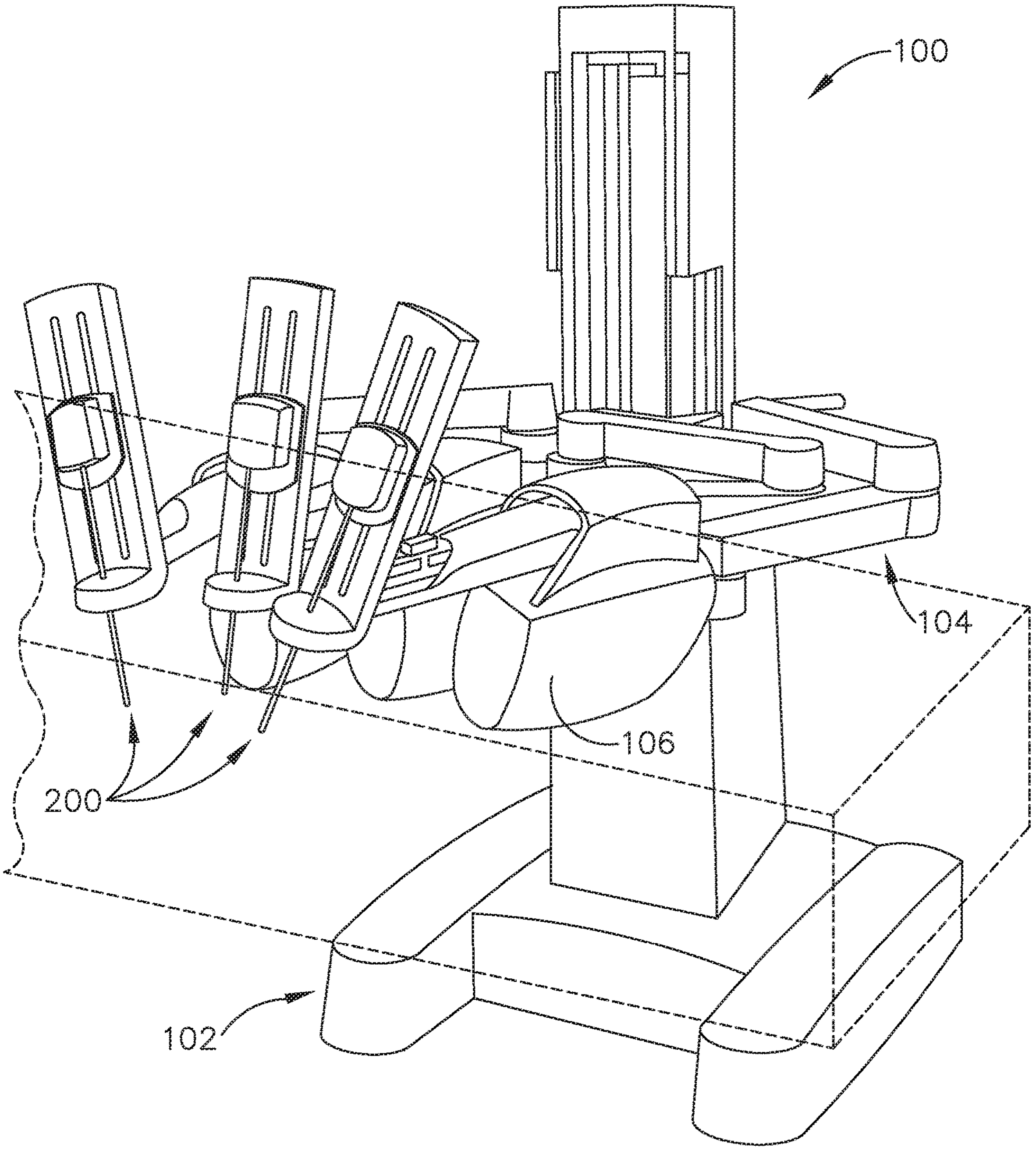

FIG. 2

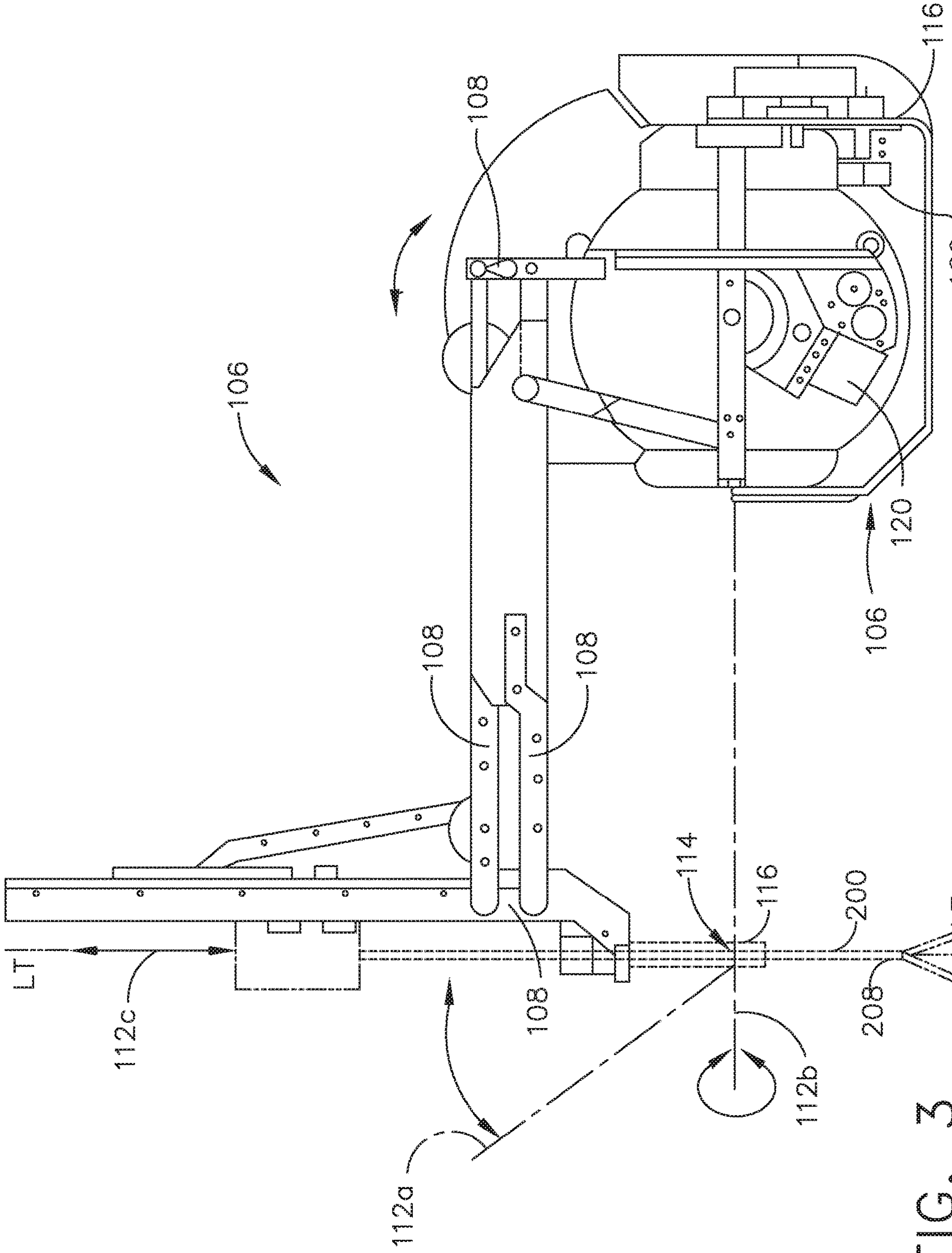
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FIG. 3

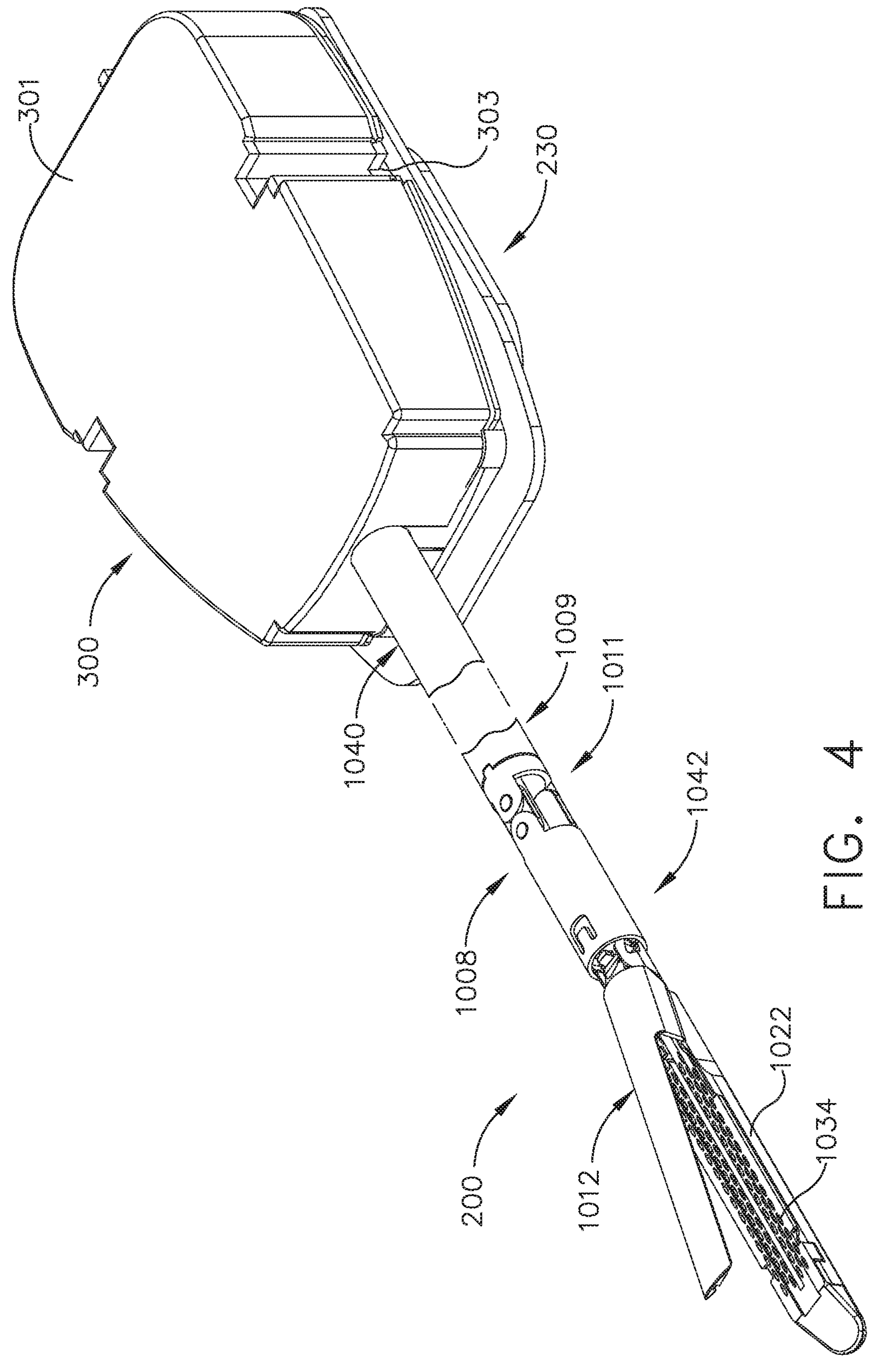
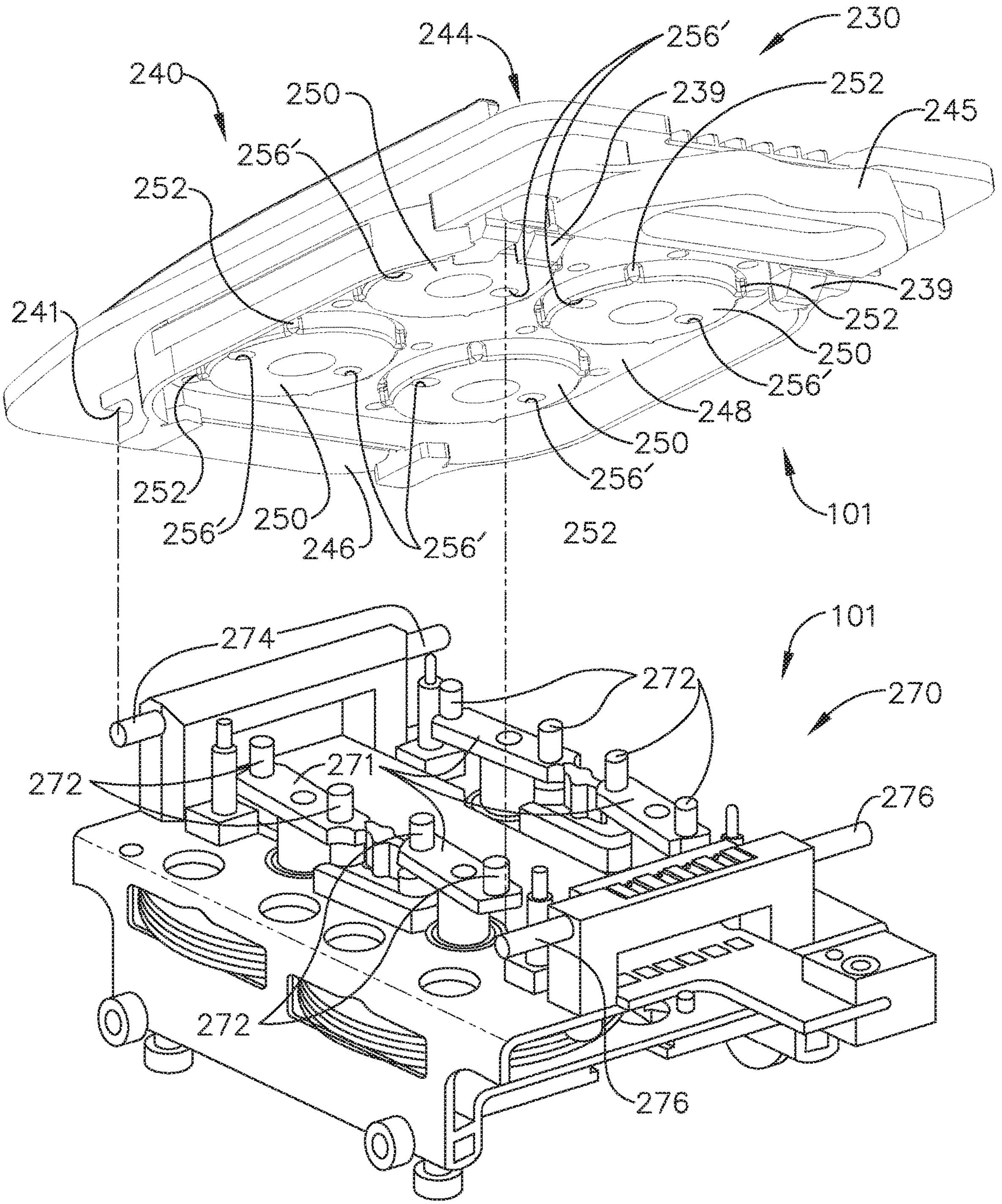


FIG. 4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274
101
272
270
272
271
276
272
276

FIG. 5

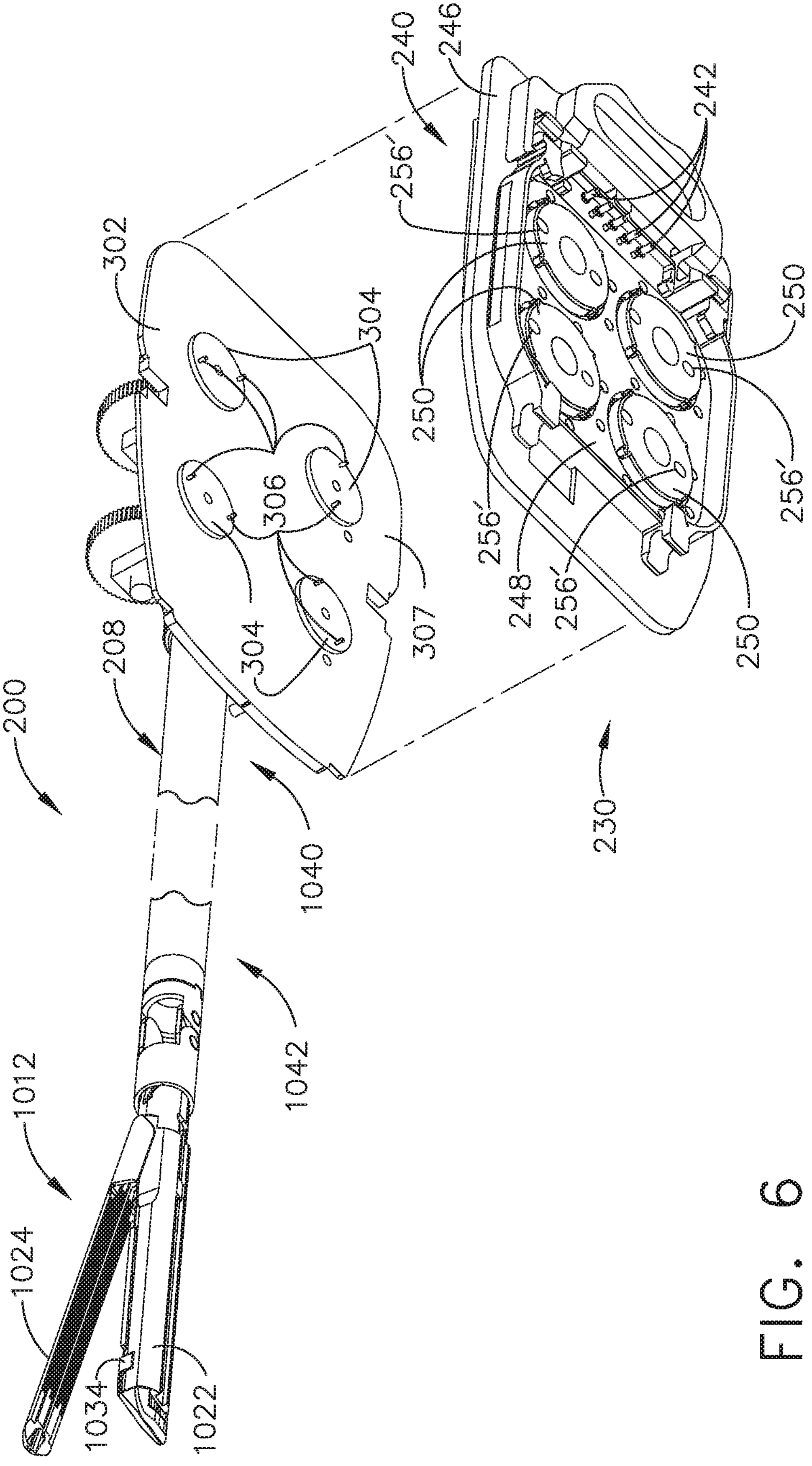
300
302
304
304
306
304
304
307
240
246
242
256'
250
250
250
256'
256'
248
256'
250
208
200
1040
230
1042
1012
1024
1034
1022

FIG. 6

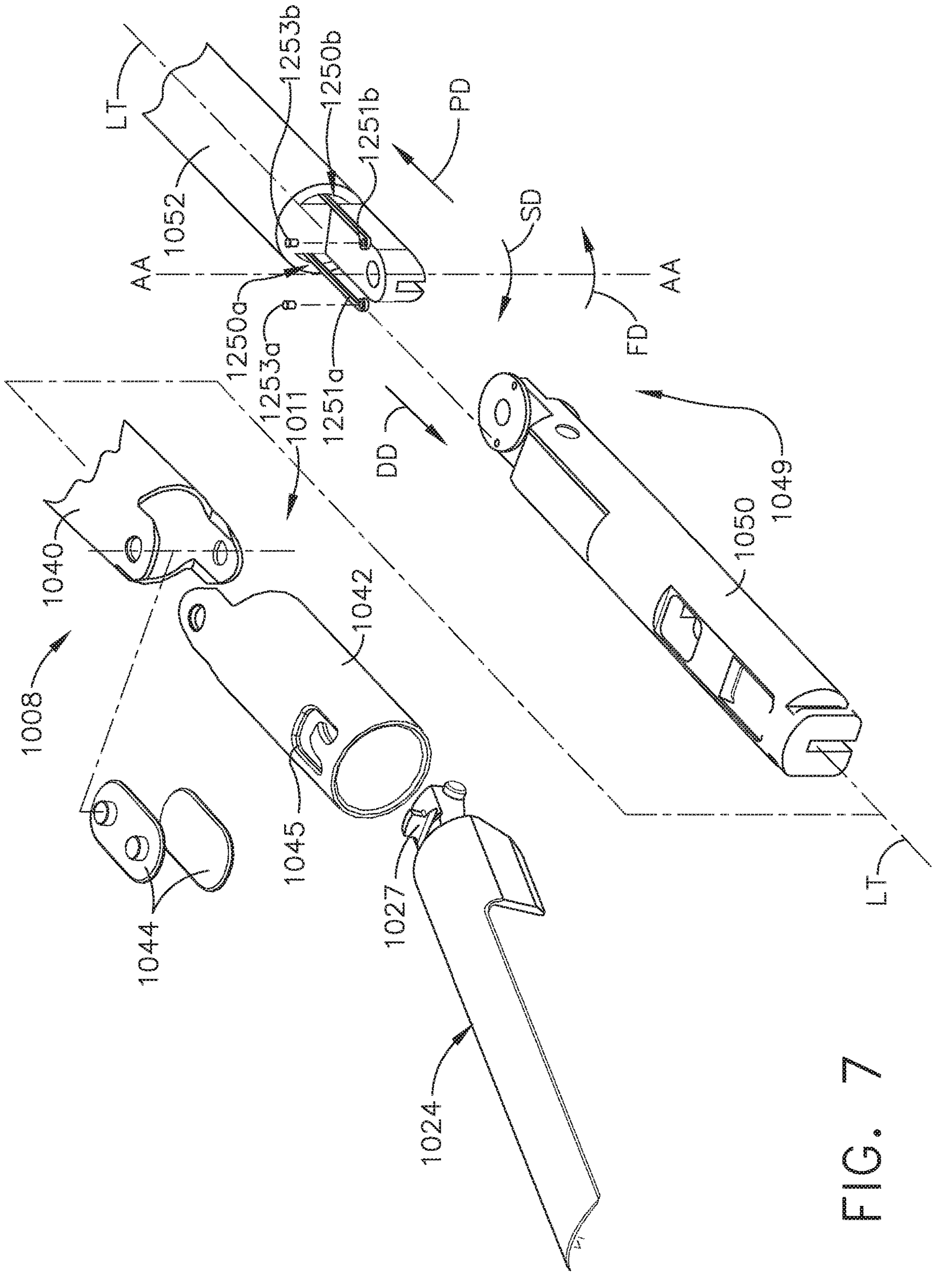
LT
1253b
1250b
1251b
PD
1052
AA
SD
AA
FD
1250a
1253a
1011
1251a
DD
1049
1050
1040
1042
1008
1045
1044
1027
1024
LT

FIG. 7

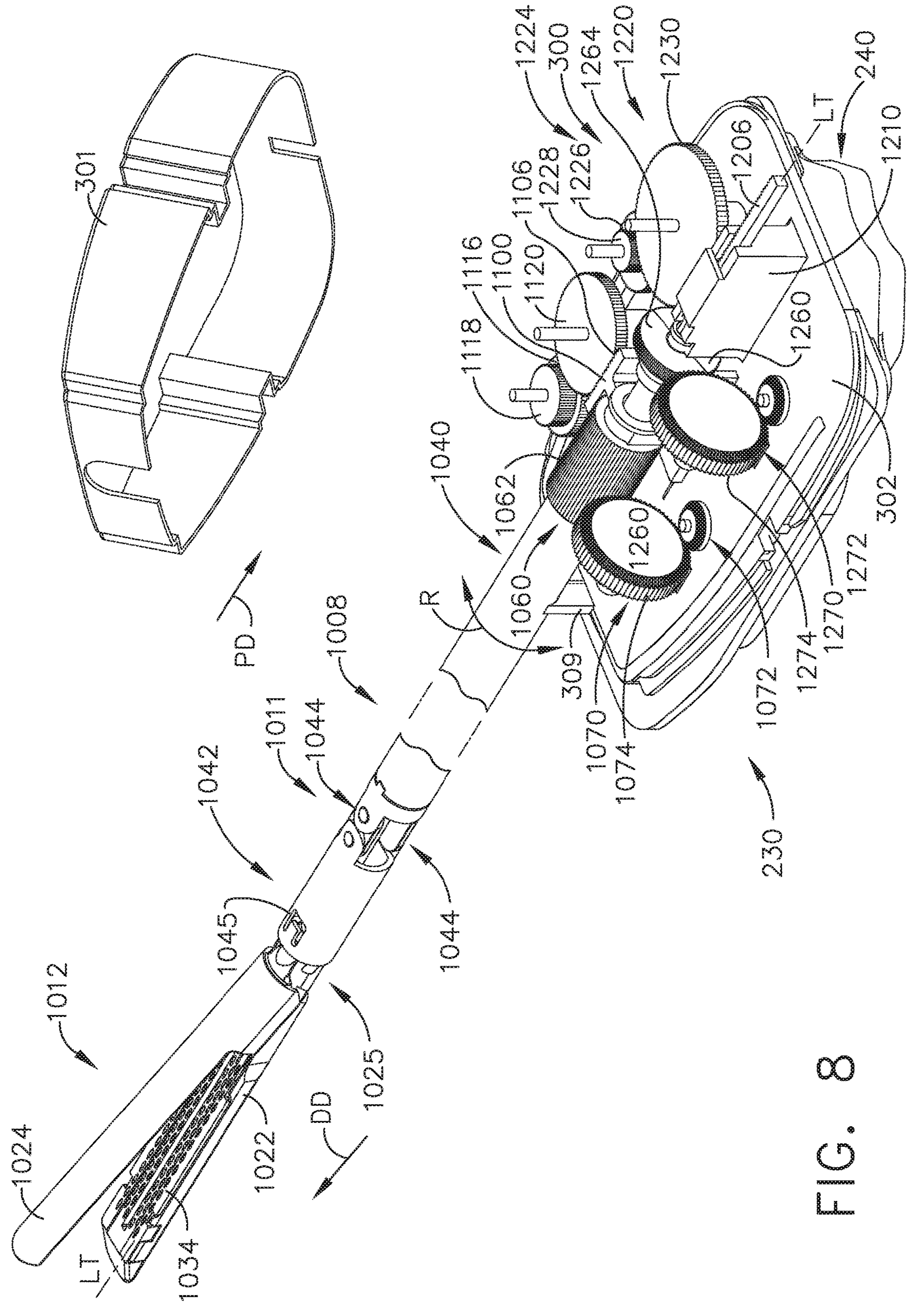
301
1224
300
1264
1220
1230
240
LT
1210
1206
1226
1228
1106
1100
1116
1120
1118
1260
1260
302
1040
1062
1060
R
1272
1270
1274
1072
309
1070
1074
1008
PD
230
1011
1044
1042
1044
1045
1012
1025
1022
DD
1024
1034
LT

FIG. 8

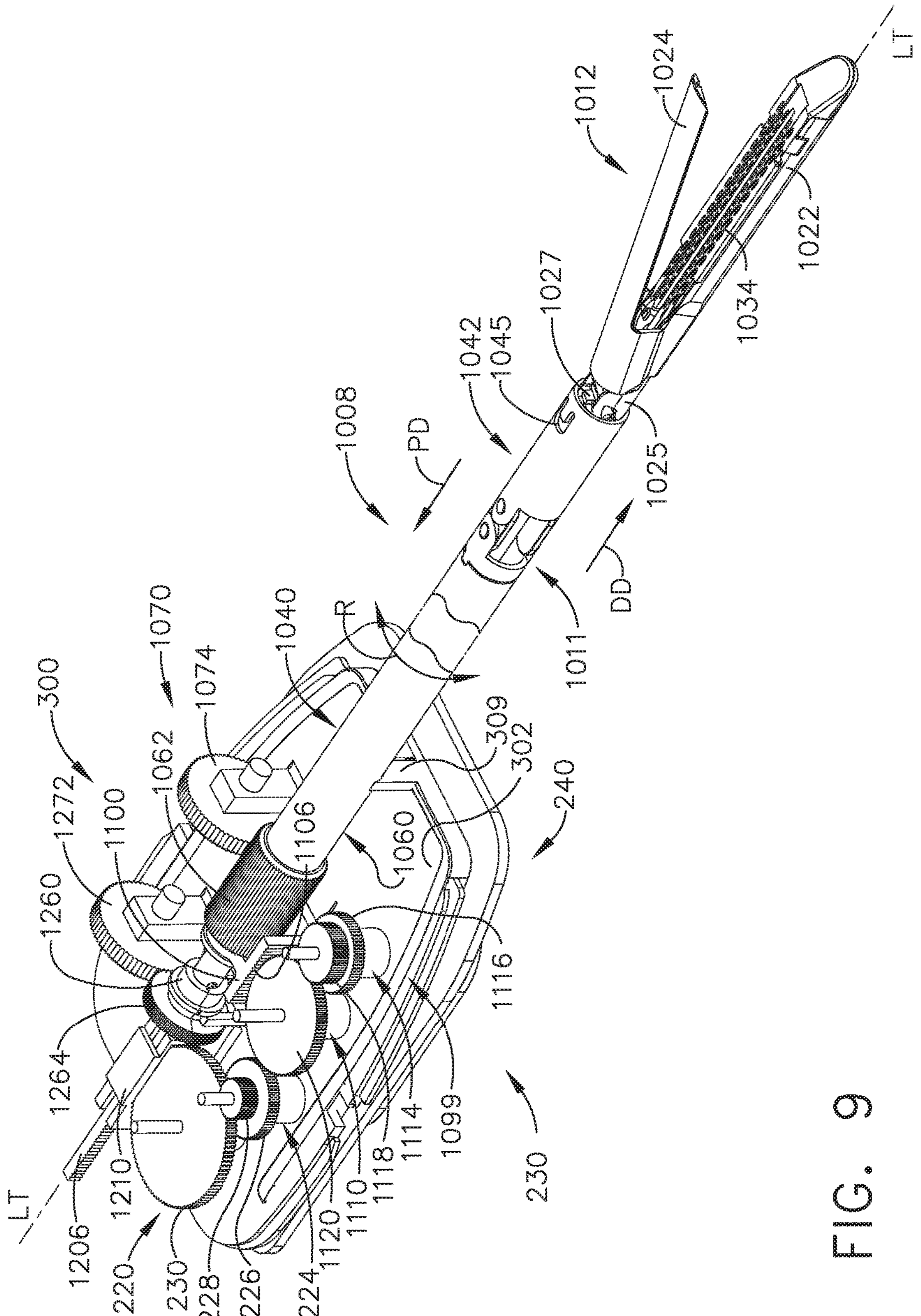
LT
1024
1012
1022
1034
1027
1042
1045
1025
1008
PD
DD
1011
1070
1074
1040
R
300
309
302
240
1062
1272
1100
1106
1060
1260
1264
1116
1099
1114
1118
1110
1120
1224
1226
1228
1230
1220
1206
1210
230
LT

FIG. 9

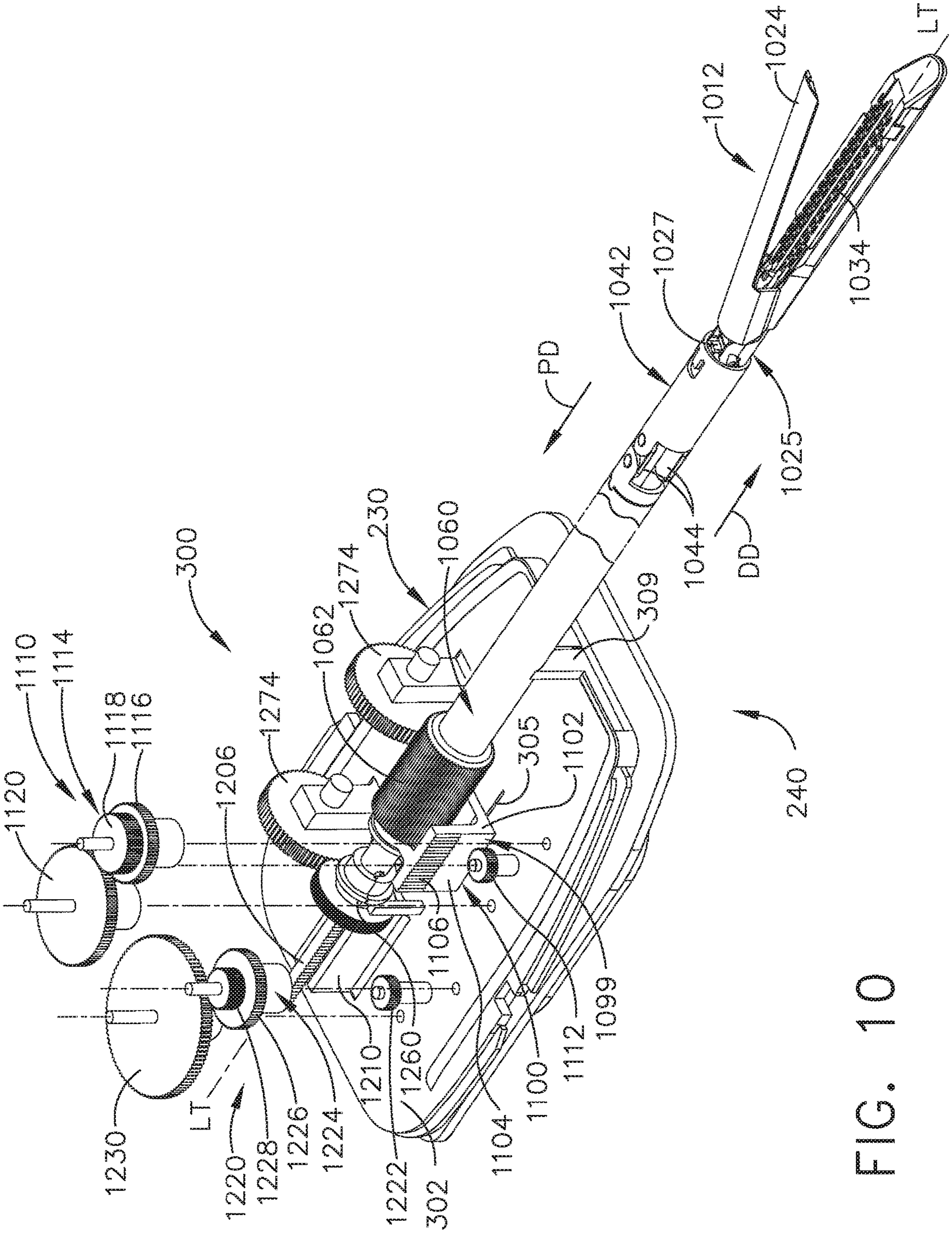
1110
1114
1118
1116
1120
1230
1220
1228
1226
1224
LT
1206
1274
1062
1274
230
1060
300
1210
1260
1222
302
1106
1104
1100
1112
1099
305
1102
309
240
1044
DD
1025
PD
1042
1027
1034
1012
1024
LT

FIG. 10

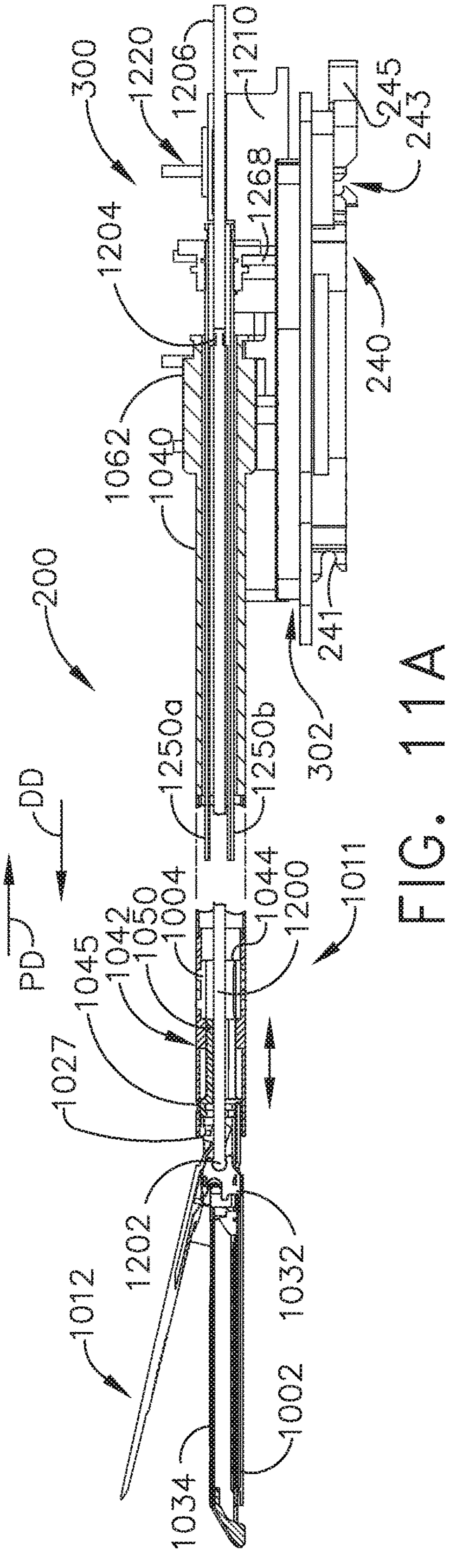

FIG. 11A

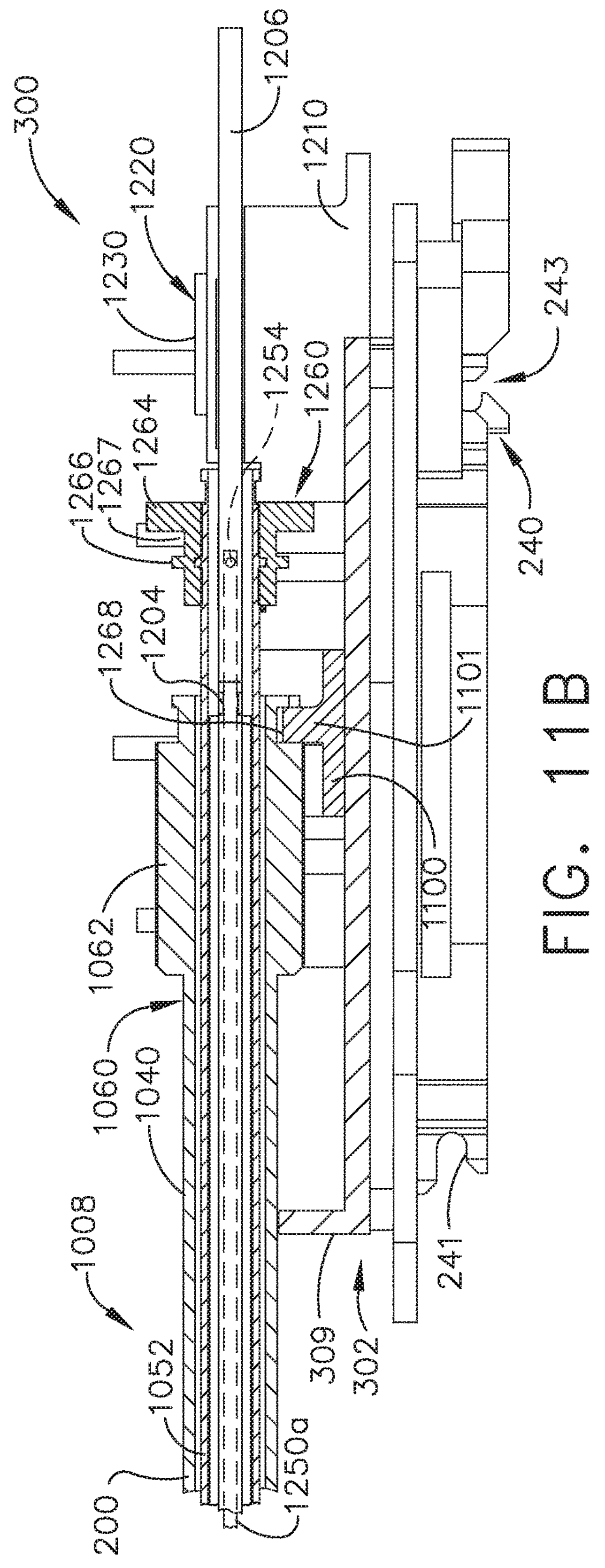

FIG. 11B

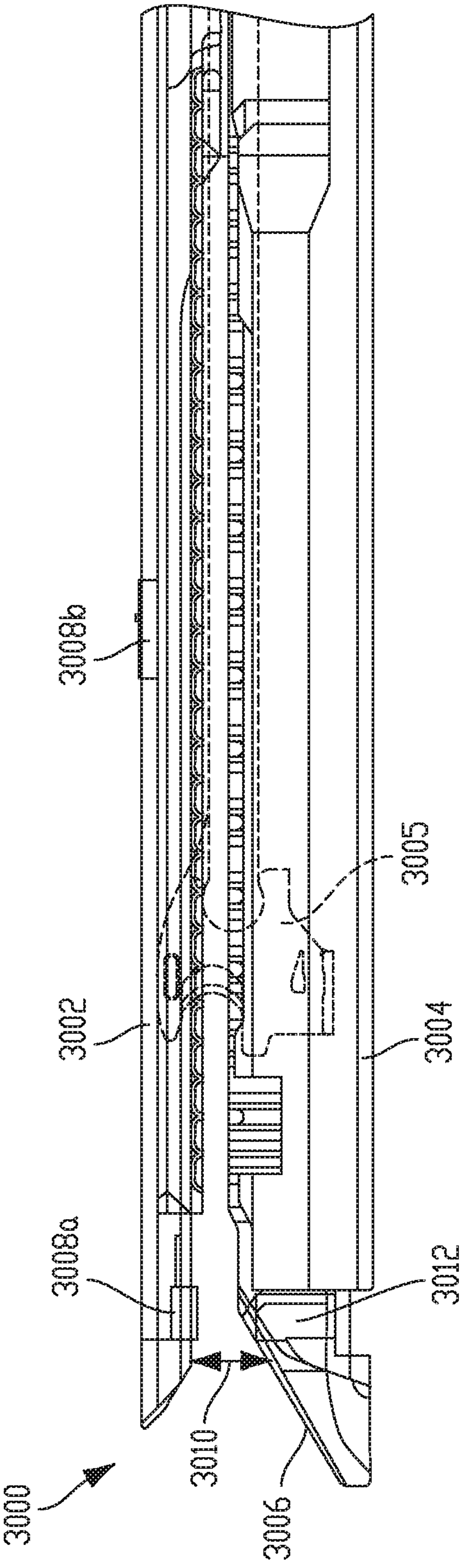

FIG. 12

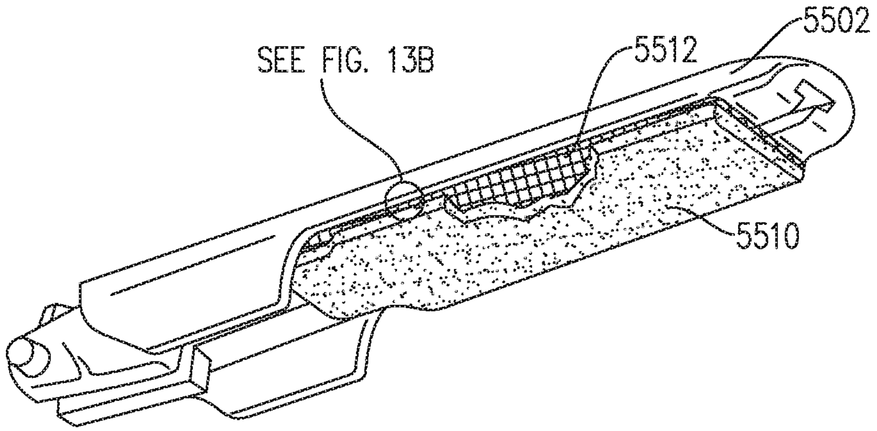

FIG. 13A

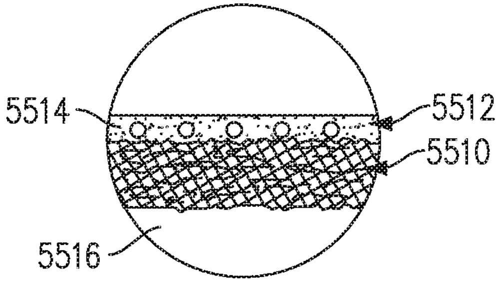

FIG. 13B

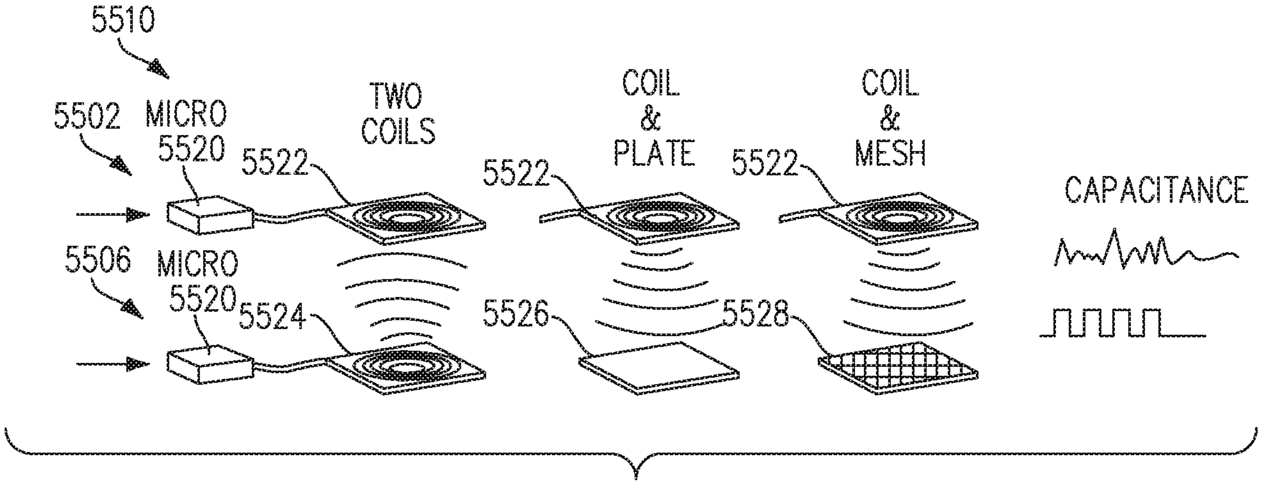

FIG. 13C

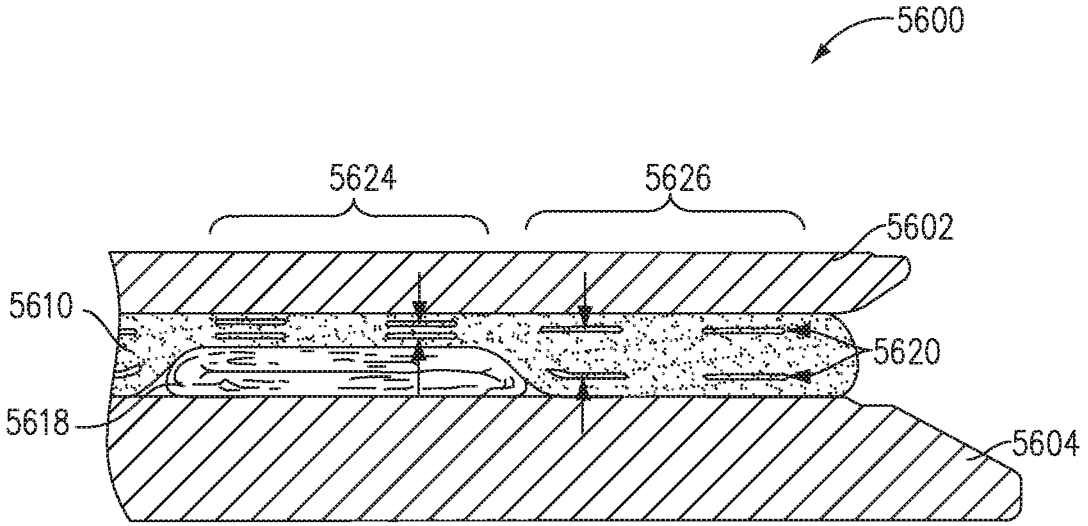

FIG. 14A

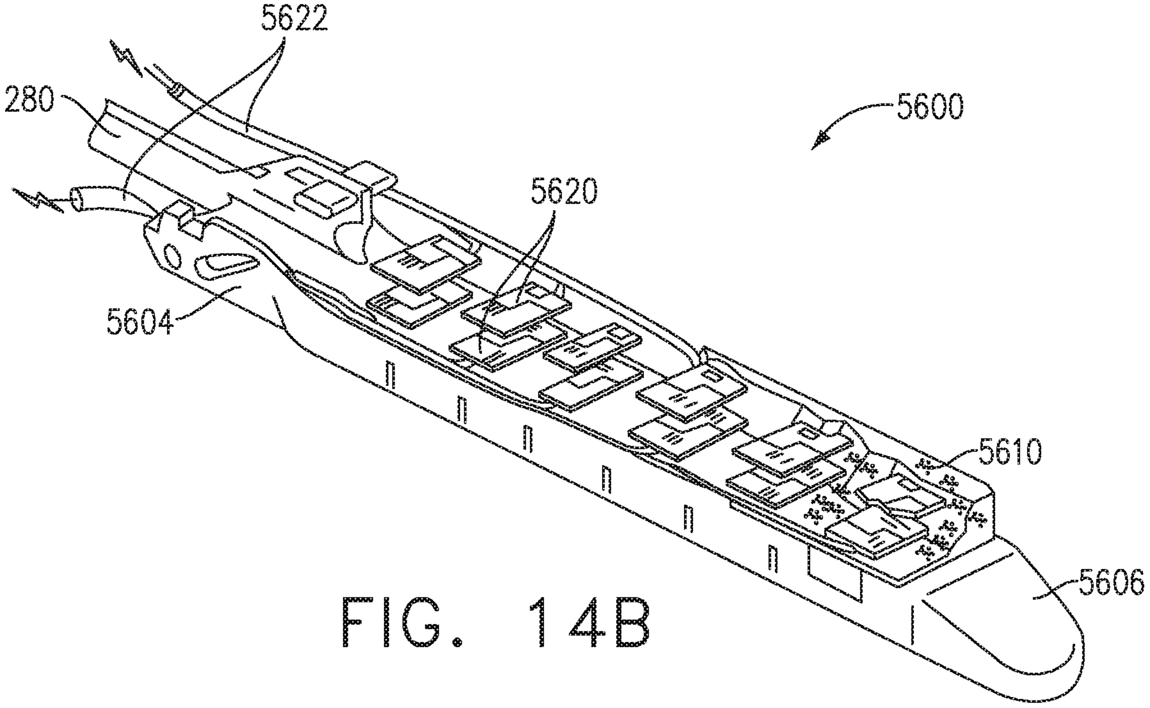

FIG. 14B

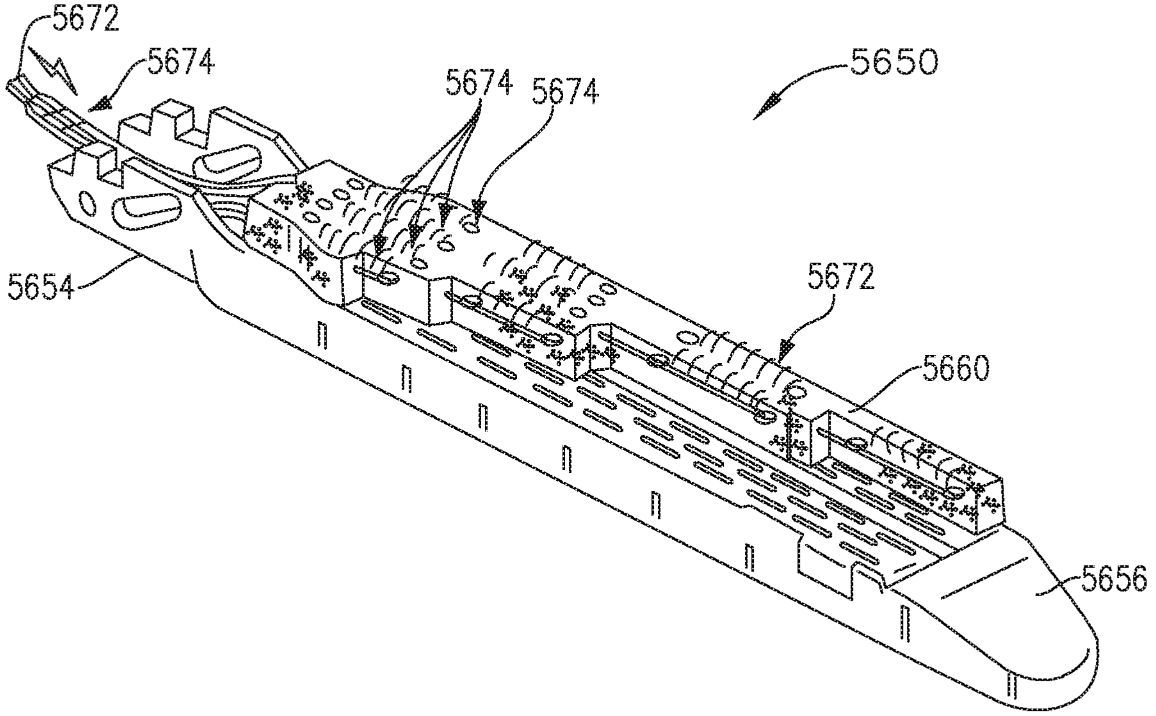

FIG. 15A

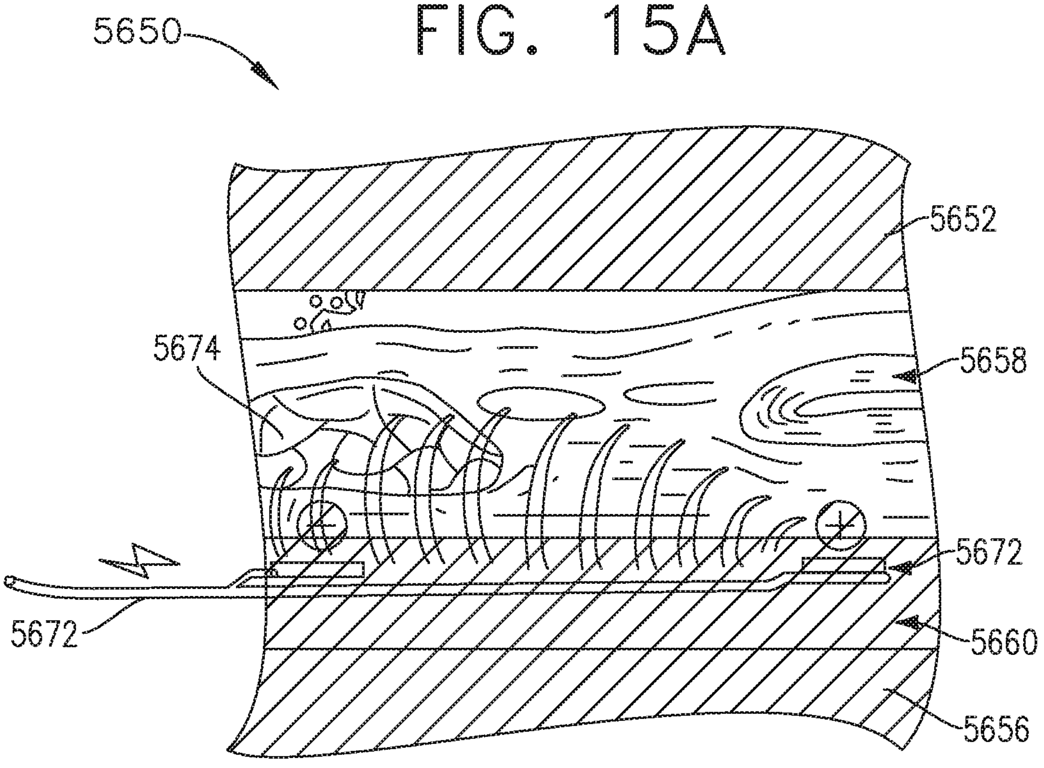

FIG. 15B

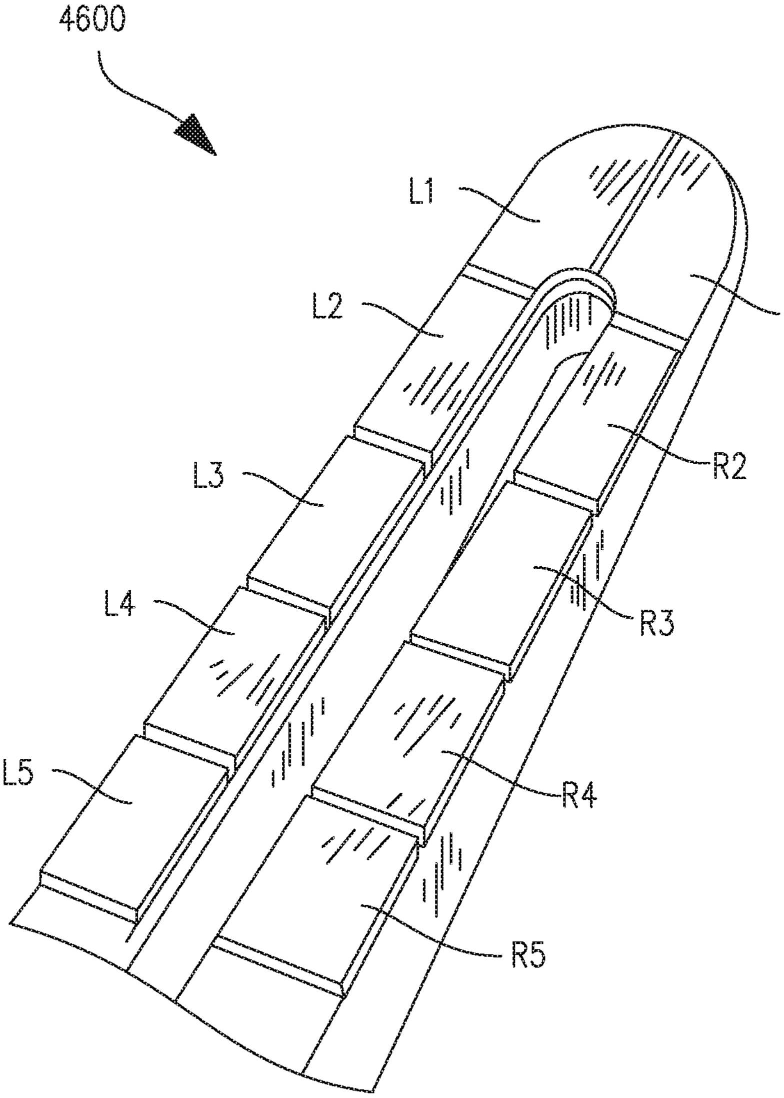

FIG. 16

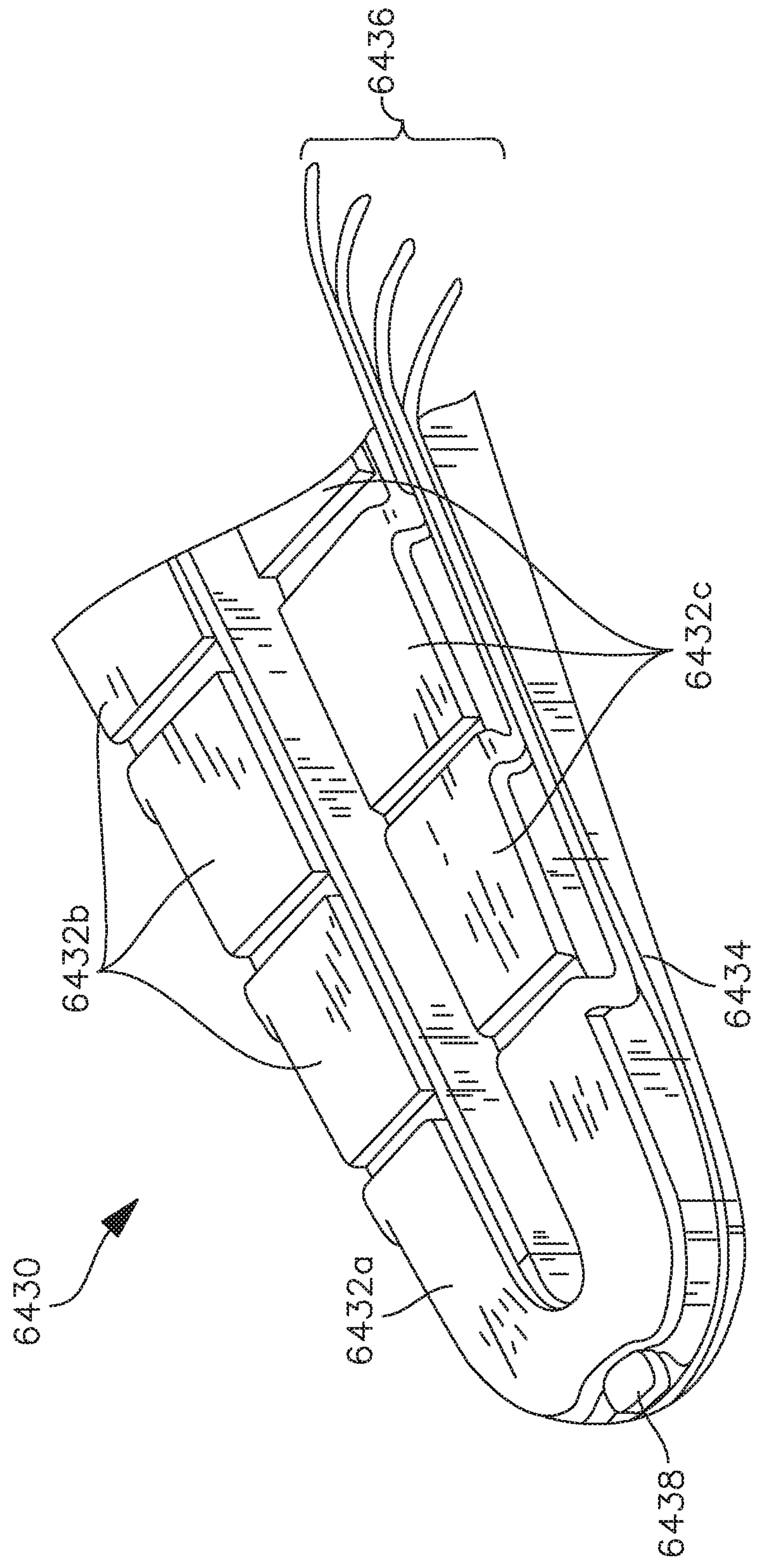

FIG. 17

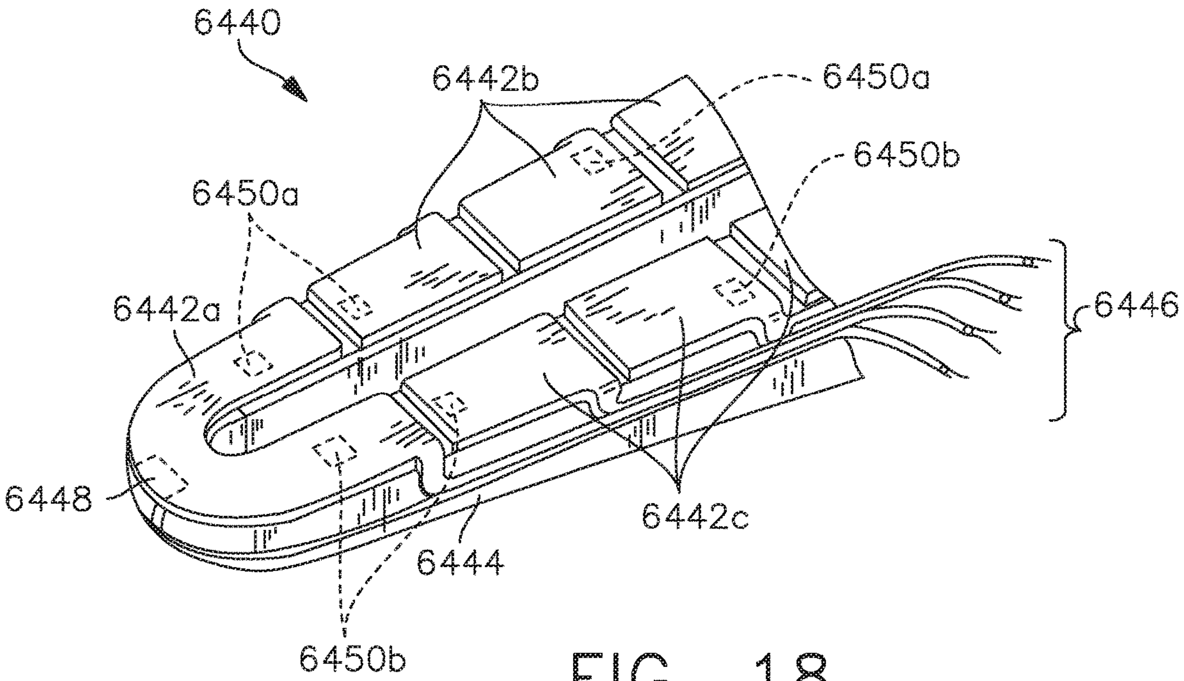
6440
6442b
6450a
6450b
6450a
6446
6442a
6448
6442c
6444
6450b

FIG. 18

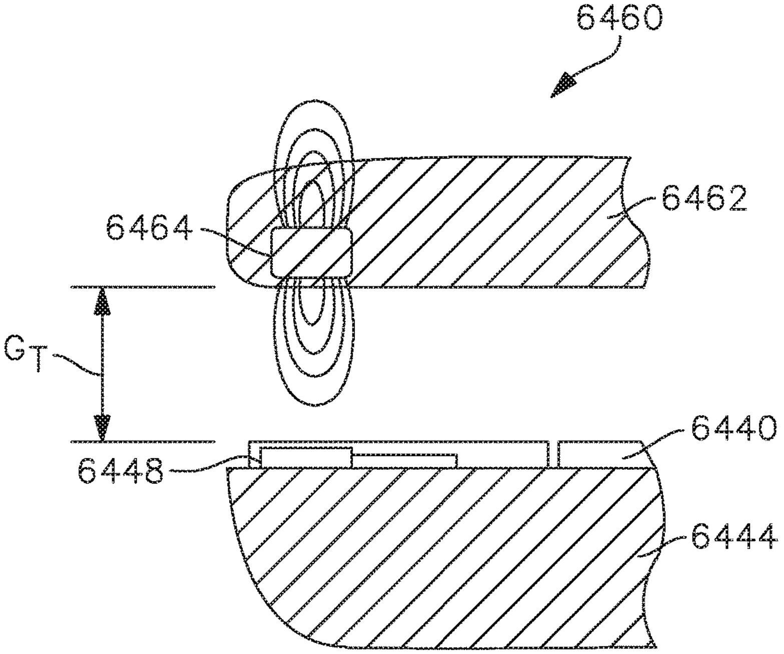
6460
6462
6464
G_T
6440
6448
6444

FIG. 19

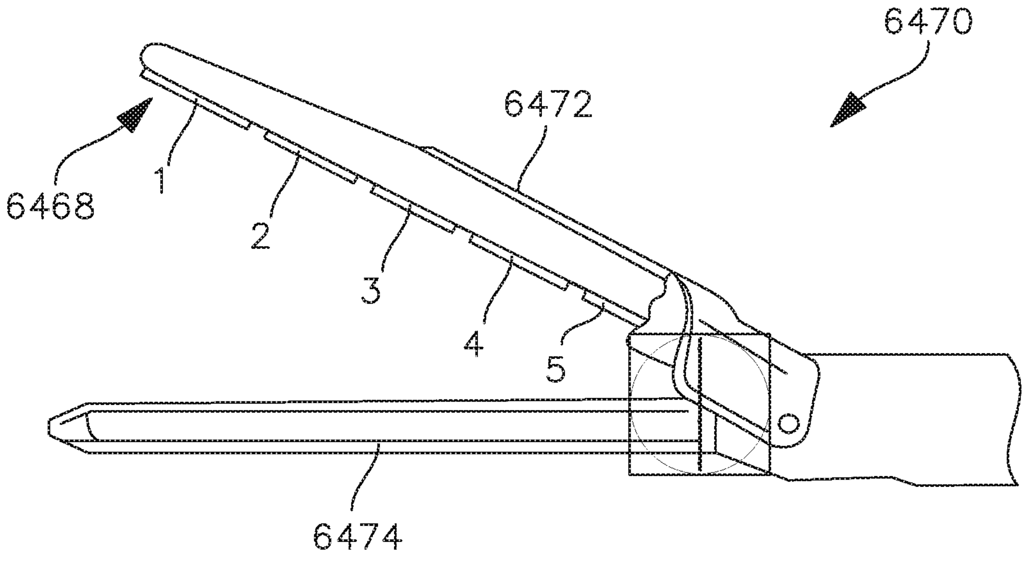
6470
6472
6468
1
2
3
4
5
6474

FIG. 20

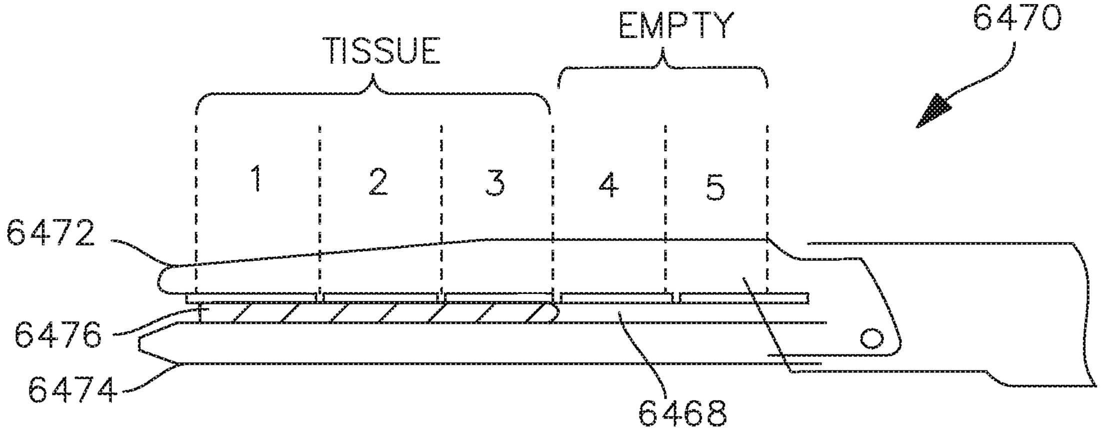
TISSUE
EMPTY
6470
1
2
3
4
5
6472
6476
6474
6468

FIG. 21

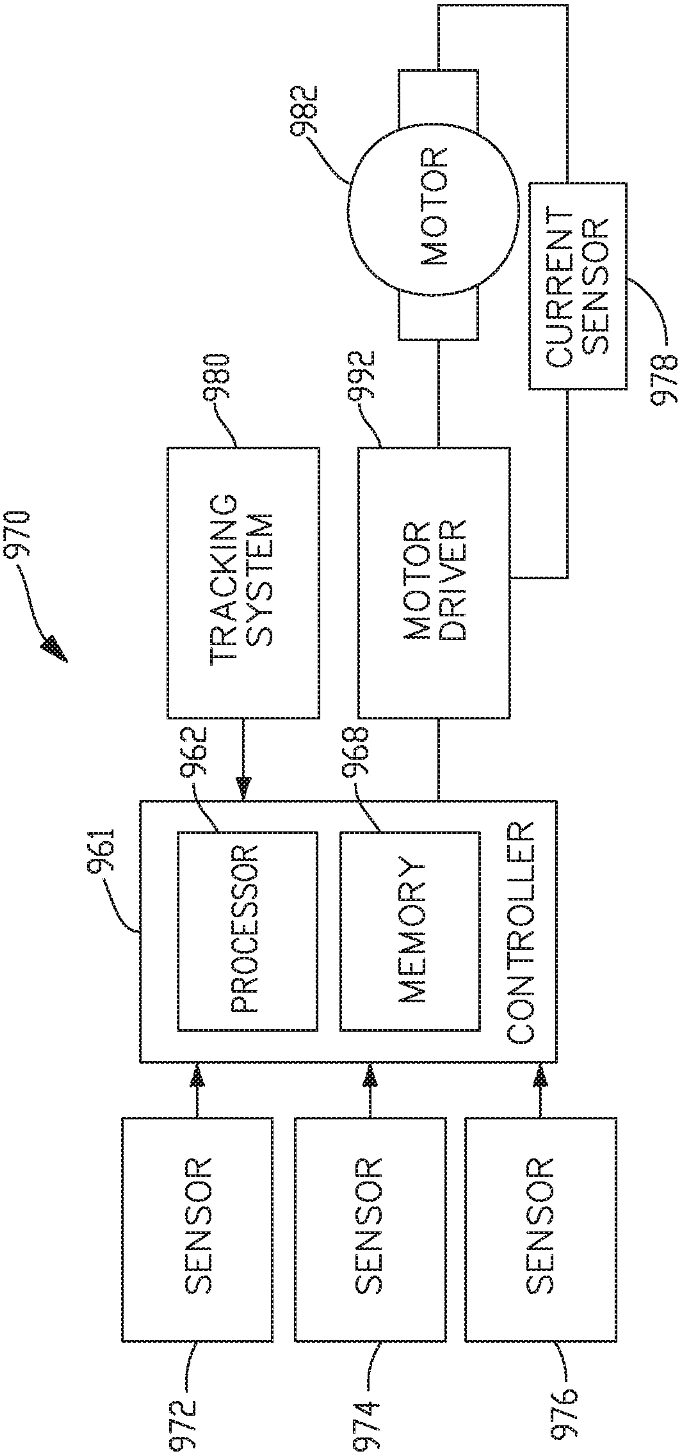
970
TRACKING SYSTEM
980
MOTOR DRIVER
992
MOTOR
982
CURRENT SENSOR
978
CONTROLLER
961
PROCESSOR
962
MEMORY
968
SENSOR
972
SENSOR
974
SENSOR
976

FIG. 22

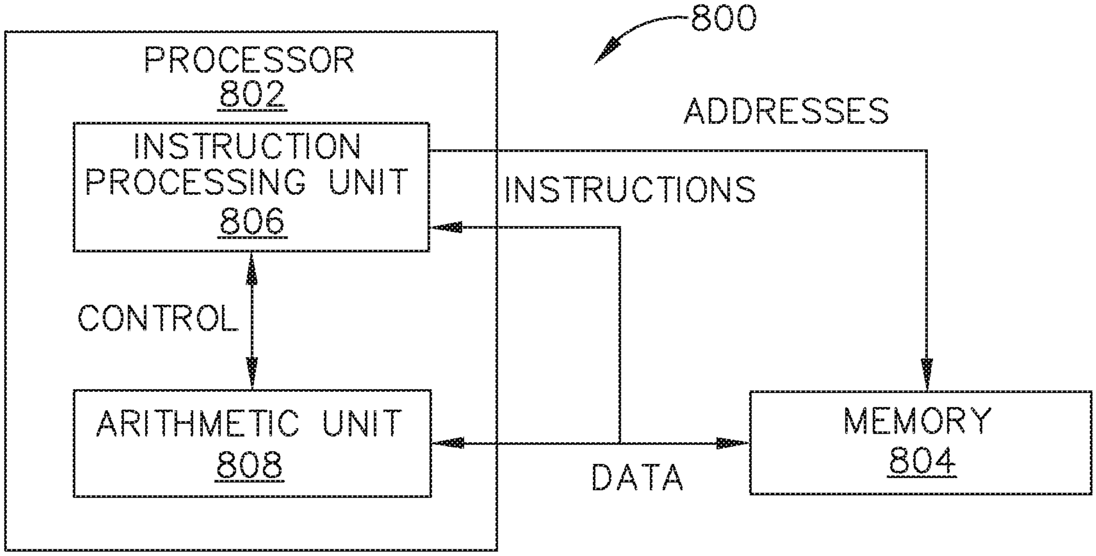

FIG. 23

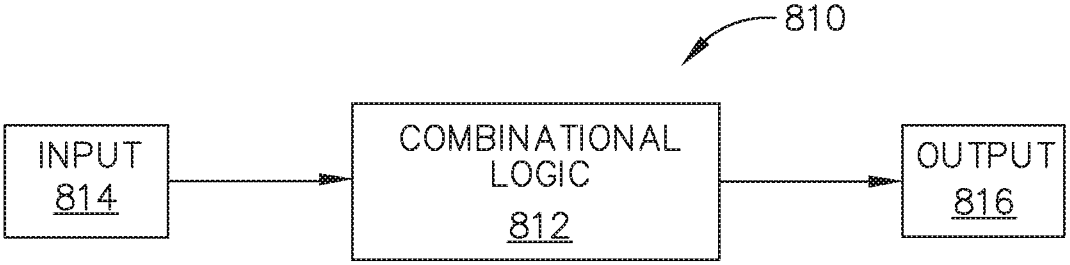

FIG. 24

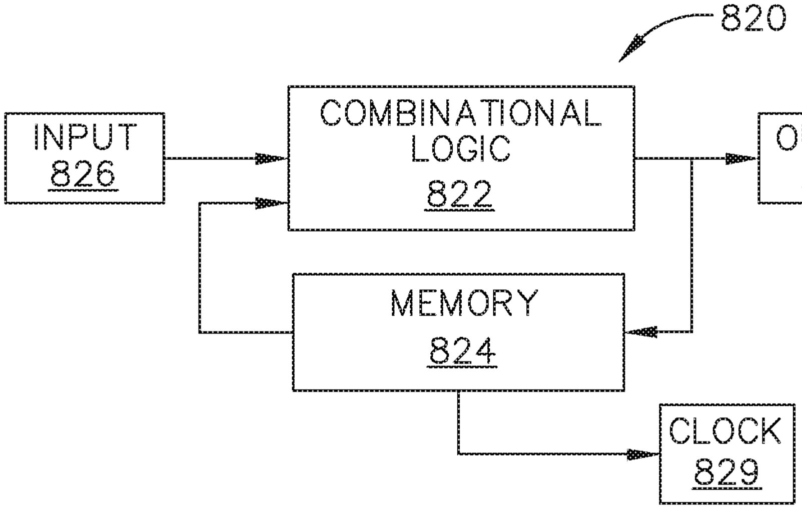

FIG. 25

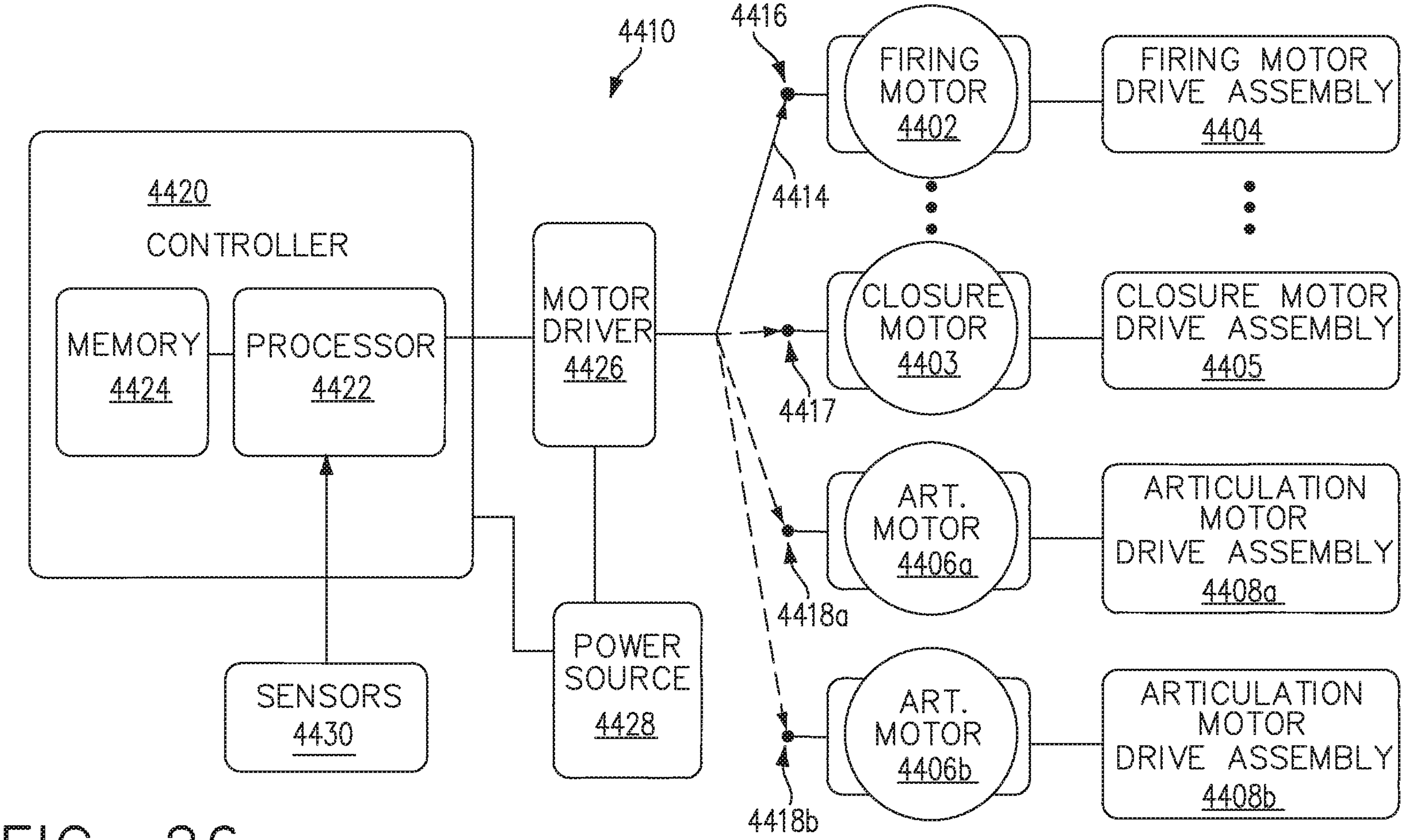
4410
4420
CONTROLLER
MEMORY
4424
PROCESSOR
4422
MOTOR DRIVER
4426
POWER SOURCE
4428
SENSORS
4430
4416
4414
4417
4418a
4418b
FIRING MOTOR
4402
CLOSURE MOTOR
4403
ART. MOTOR
4406a
ART. MOTOR
4406b
FIRING MOTOR DRIVE ASSEMBLY
4404
CLOSURE MOTOR DRIVE ASSEMBLY
4405
ARTICULATION MOTOR DRIVE ASSEMBLY
4408a
ARTICULATION MOTOR DRIVE ASSEMBLY
4408b

FIG. 26

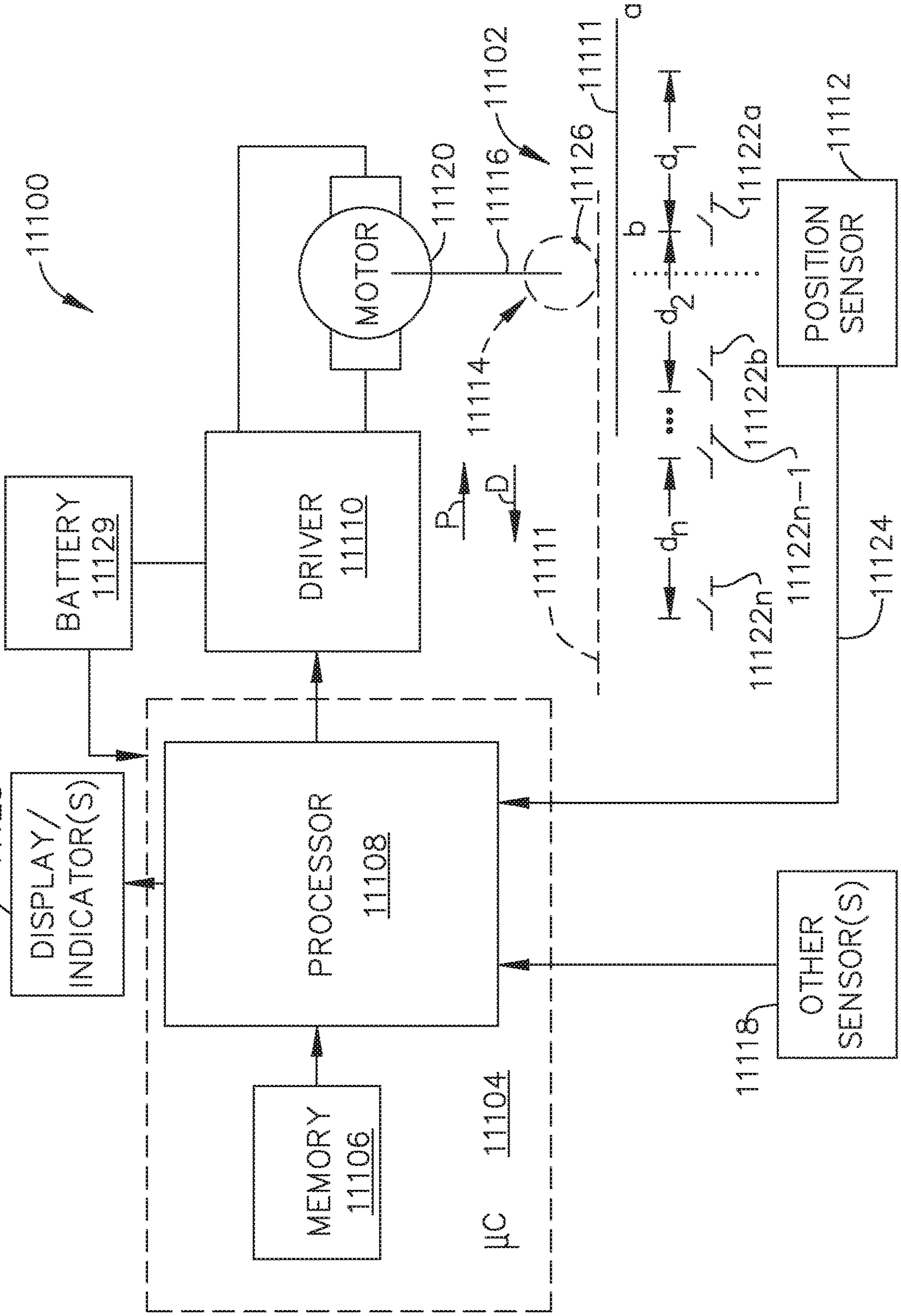
11100
BATTERY
11129
DRIVER
11110
MOTOR
11120
11116
11102
11126
11111
a
b
d_1
d_2
d_n
...
11122a
11122b
11122n−1
11122n
11114
P
D
11111
POSITION SENSOR
11112
11124
DISPLAY/ INDICATOR(S)
11128
PROCESSOR
11108
OTHER SENSOR(S)
11118
MEMORY
11106
µC
11104

FIG. 27

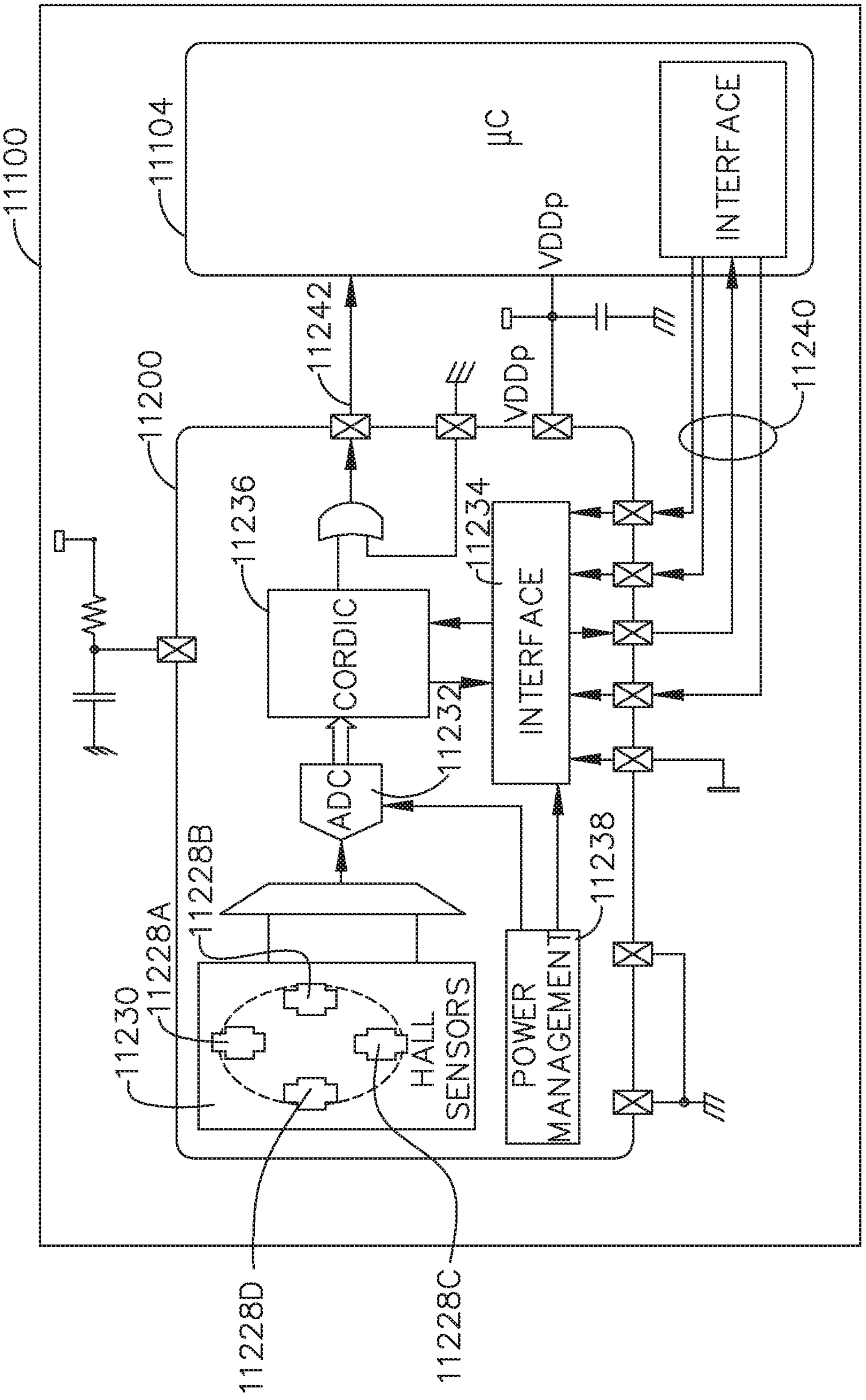
11100
11104
μC
INTERFACE
VDDp
11242
11200
VDDp
11240
11236
11234
CORDIC
INTERFACE
11232
ADC
11238
POWER MANAGEMENT
11228B
11228A
11230
HALL SENSORS
11228D
11228C

FIG. 28

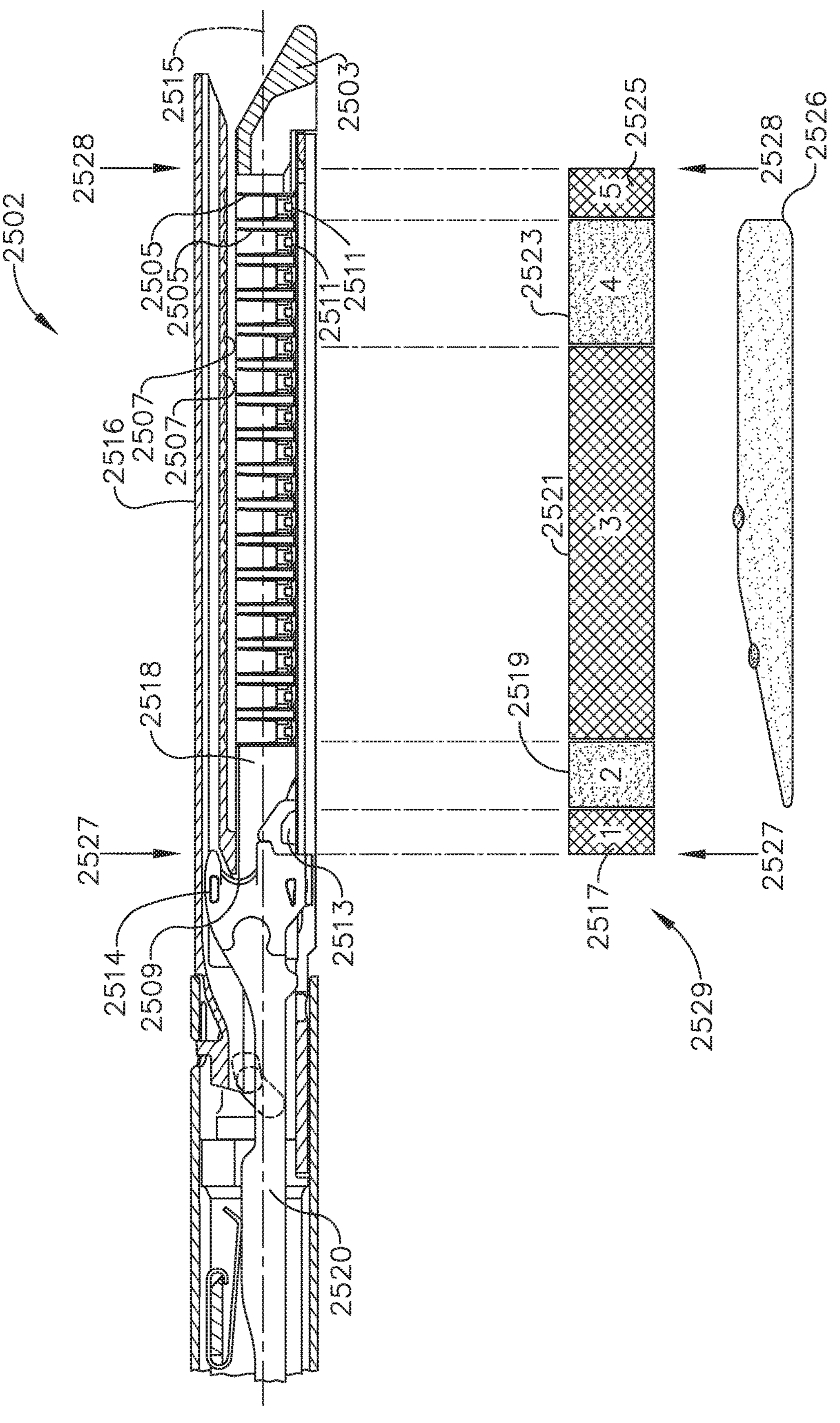
2502
2515
2503
2528
2525
2528
2526
2505
2505
2511
2511
2523
5
4
2507
2507
2516
2521
3
2518
2519
2
2527
2527
1
2517
2514
2509
2513
2529
2520

FIG. 29

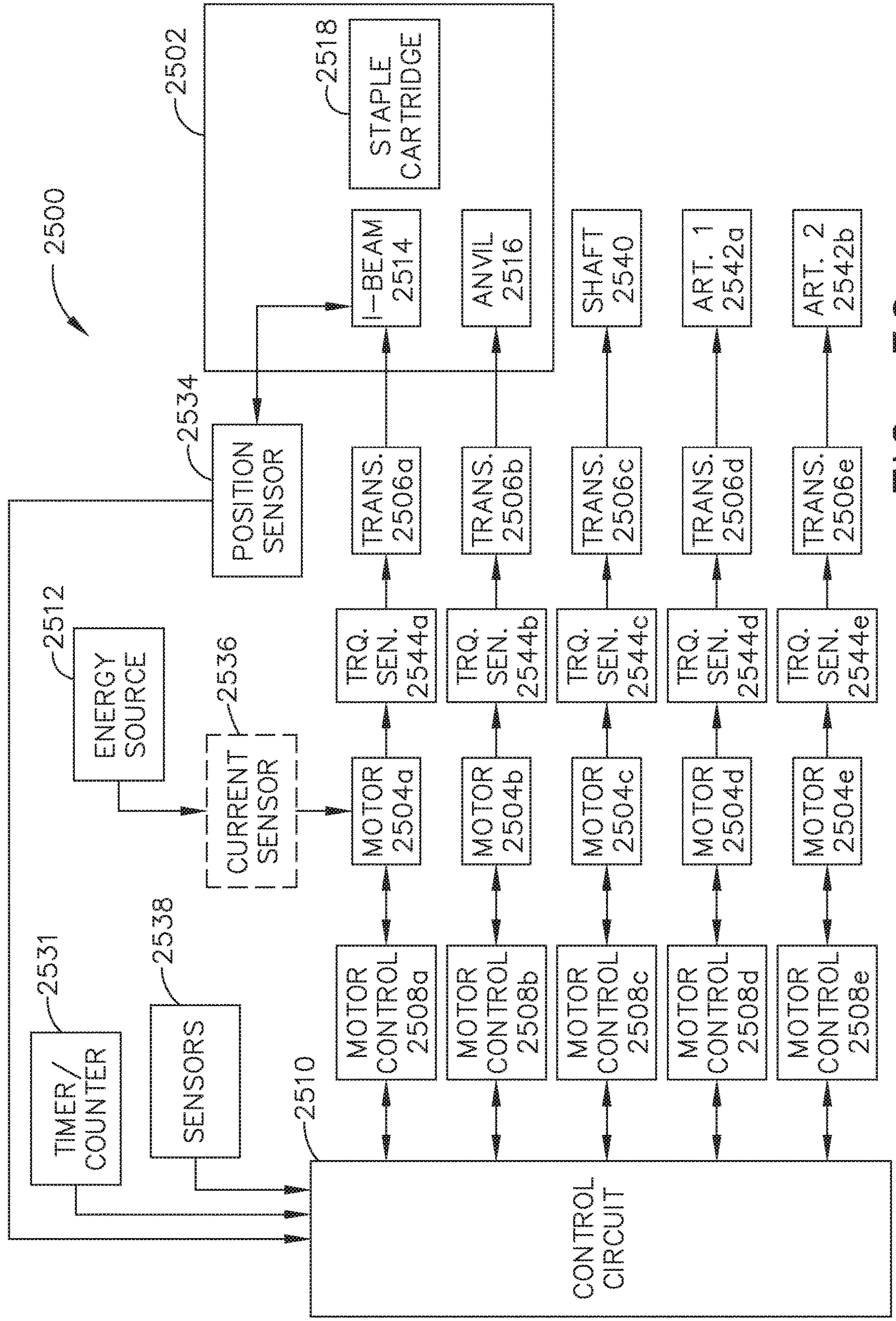
2500
2502
STAPLE CARTRIDGE
2518
I—BEAM 2514
ANVIL 2516
SHAFT 2540
ART. 1 2542a
ART. 2 2542b
2534
POSITION SENSOR
TRANS. 2506a
TRANS. 2506b
TRANS. 2506c
TRANS. 2506d
TRANS. 2506e
2512
ENERGY SOURCE
2536
CURRENT SENSOR
TRQ. SEN. 2544a
TRQ. SEN. 2544b
TRQ. SEN. 2544c
TRQ. SEN. 2544d
TRQ. SEN. 2544e
MOTOR 2504a
MOTOR 2504b
MOTOR 2504c
MOTOR 2504d
MOTOR 2504e
2538
2531
SENSORS
TIMER/ COUNTER
MOTOR CONTROL 2508a
MOTOR CONTROL 2508b
MOTOR CONTROL 2508c
MOTOR CONTROL 2508d
MOTOR CONTROL 2508e
2510
CONTROL CIRCUIT

FIG. 30

12000

12002 12004 12006

FIRING	FROM CLOSURE		FROM FIRING	
	INITIAL VELOCITY SELECTION		FIRING VELOCITY UPDATES	
VARIABLE	SLOW	FAST	DECREASE	INCREASE
GAP	+ +	− −	+	−
F2F/C	+ +	− −	+ +	− −
KNIFE VELOCITY	/	/	−	+
IMPEDANCE	+ +	− −	+	+
CARTRIDGE COVERAGE	+	−	+	+

FIG. 31

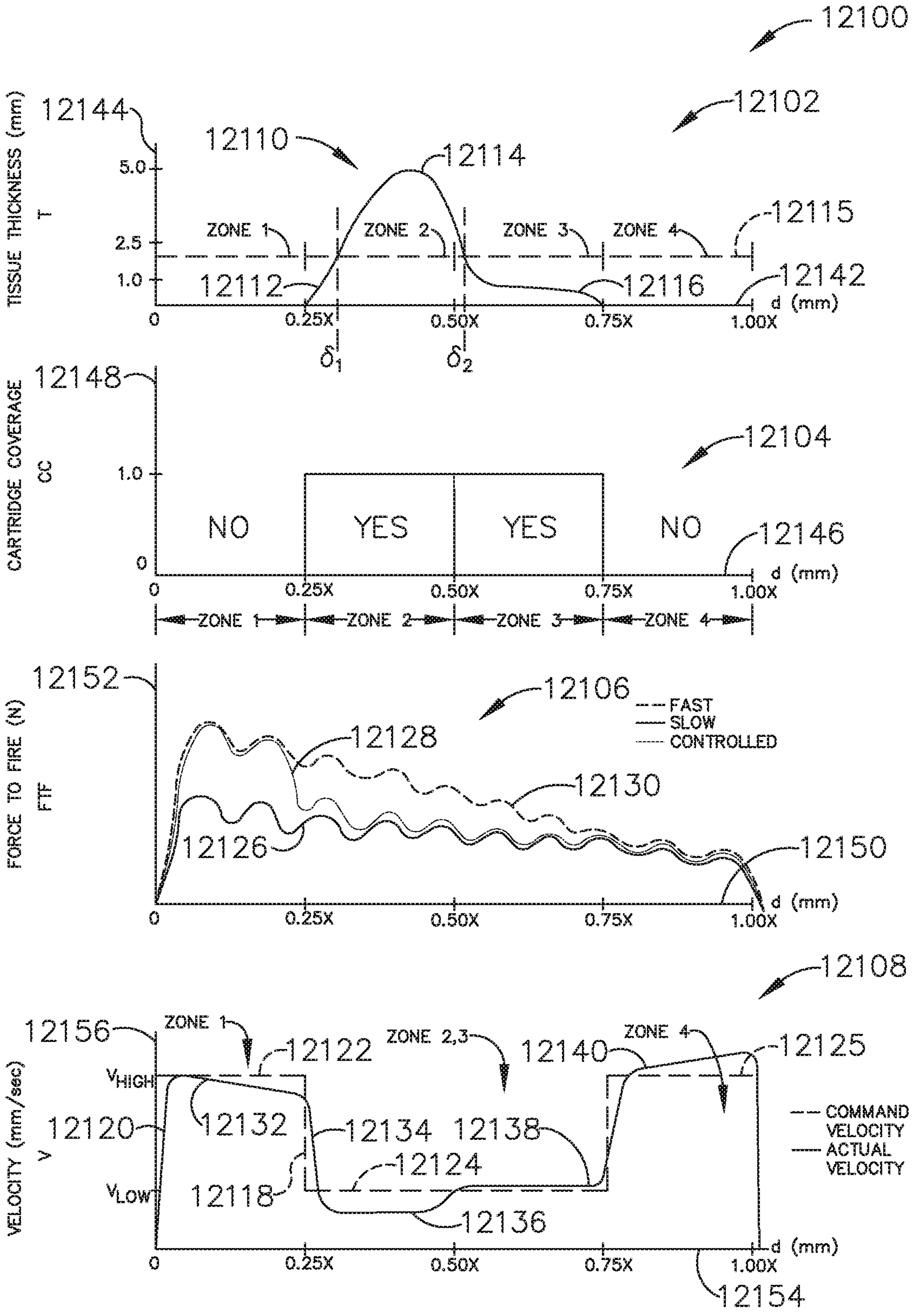
12100
12102
12144
12110
12114
TISSUE THICKNESS (mm)
T
5.0
2.5
1.0
ZONE 1
ZONE 2
ZONE 3
ZONE 4
12115
12112
12116
12142
0
0.25X
0.50X
0.75X
1.00X
d (mm)
δ_1
δ_2
12148
CARTRIDGE COVERAGE
CC
1.0
0
12104
NO
YES
YES
NO
12146
ZONE 1
ZONE 2
ZONE 3
ZONE 4
12152
12106
FORCE TO FIRE (N)
FTF
FAST
SLOW
CONTROLLED
12128
12130
12126
12150
12108
12156
ZONE 1
12122
ZONE 2,3
12140
ZONE 4
12125
VELOCITY (mm/sec)
V
V_{HIGH}
V_{LOW}
12120
12132
12134
12138
12124
12118
12136
COMMAND VELOCITY
ACTUAL VELOCITY
12154

FIG. 32

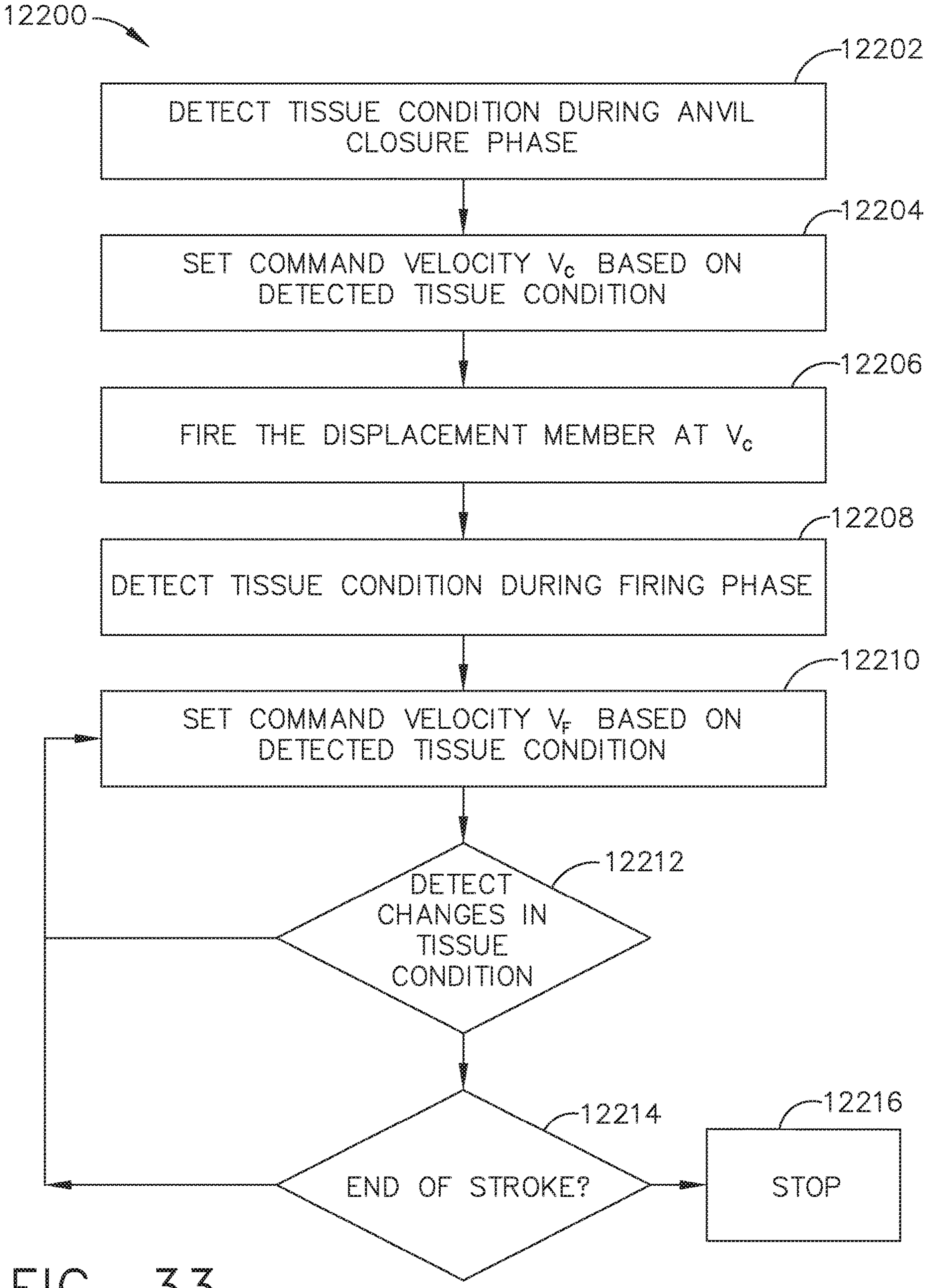
12200
12202
DETECT TISSUE CONDITION DURING ANVIL CLOSURE PHASE
12204
SET COMMAND VELOCITY V_C BASED ON DETECTED TISSUE CONDITION
12206
FIRE THE DISPLACEMENT MEMBER AT V_C
12208
DETECT TISSUE CONDITION DURING FIRING PHASE
12210
SET COMMAND VELOCITY V_F BASED ON DETECTED TISSUE CONDITION
12212
DETECT CHANGES IN TISSUE CONDITION
12214
END OF STROKE?
12216
STOP

FIG. 33

CLOSED LOOP VELOCITY CONTROL TECHNIQUES BASED ON SENSED TISSUE PARAMETERS FOR ROBOTIC SURGICAL INSTRUMENT

TECHNICAL FIELD

The present disclosure relates to robotic surgical instruments and, in various circumstances, to robotic surgical stapling and cutting instruments and staple cartridges therefor that are designed to staple and cut tissue.

BACKGROUND

In a motorized robotic surgical stapling and cutting instrument it may be useful to measure the position and velocity of a cutting member in an initial predetermined time or displacement to control speed. Measurement of position or velocity over an initial predetermined time or displacement may be useful to evaluate tissue thickness and to adjust the speed of the remaining stroke based on this comparison against a threshold.

SUMMARY

In one aspect, a robotic surgical system is provided. The robotic surgical system comprises a control circuit configured to: detect a condition at an end effector during a closure phase; set command velocity of a motor coupled to a displacement member coupled to the end effector based on the detected condition at the end effector during the closure phase; fire the displacement member at the set command velocity; detect a condition at the end effector during a firing phase; and set command velocity of the motor based on the condition detected at the end effector during the firing phase.

In another aspect, the robotic surgical system comprises a control circuit coupled to a motor and configured to set a command velocity of the motor during a closure phase or a firing phase, wherein the motor is configured to drive a displacement member at the command velocity, wherein the control circuit is configured to: detect a first condition at the end effector; detect a second condition at the end effector; set the command velocity of the motor based on the detected first and second conditions at the end effector; and fire the displacement member at the set command velocity.

In another aspect, the robotic surgical system comprises a first motor to drive a displacement member coupled to a cutting member; a second motor to drive a closure tube coupled to an anvil portion of an end effector, wherein the closure tube is configured to close or open the anvil; and a control circuit coupled to the first and second motor, wherein control circuit is configured to set a command velocity of the first motor during a closure phase or a firing phase and set a command velocity of the second motor to apply a closure force to the closure tube coupled to the anvil, wherein the control circuit is configured to: detect a first condition at the end effector; detect a second condition at the end effector; set the first command velocity of the motor based on the detected first and second conditions at the end effector; and fire the displacement member at the first set command velocity.

FIGURES

The novel features of the aspects described herein are set forth with particularity in the appended claims. These aspects, however, both as to organization and methods of

operation may be better understood by reference to the following description, taken in conjunction with the accompanying drawings.

FIG. **1** is a perspective view of one robotic controller according to one aspect of this disclosure.

FIG. **2** is a perspective view of one robotic surgical arm cart/manipulator of a robotic surgical system operably supporting a plurality of surgical tool according to one aspect of this disclosure.

FIG. **3** is a side view of the robotic surgical arm cart/manipulator depicted in FIG. **2** according to one aspect of this disclosure.

FIG. **4** is a perspective view of a surgical tool according to one aspect of this disclosure.

FIG. **5** is an exploded assembly view of an adapter and tool holder arrangement for attaching various surgical tools according to one aspect of this disclosure.

FIG. **6** is a partial bottom perspective view of the surgical tool aspect of FIG. **4** according to one aspect of this disclosure.

FIG. **7** is a partial exploded view of a portion of an articulatable surgical end effector according to one aspect of this disclosure.

FIG. **8** is a rear perspective view of the surgical tool of FIG. **105** with the tool mounting housing removed according to one aspect of this disclosure.

FIG. **9** is a front perspective view of the surgical tool of FIG. **6** with the tool mounting housing removed according to one aspect of this disclosure.

FIG. **10** is a partial exploded perspective view of the surgical tool of FIG. **6** according to one aspect of this disclosure.

FIG. **11**A is a partial cross-sectional side view of the surgical tool of FIG. **6** according to one aspect of this disclosure.

FIG. **11**B is an enlarged cross-sectional view of a portion of the surgical tool depicted in FIG. **11**A according to one aspect of this disclosure.

FIG. **12** illustrates one aspect of an end effector comprising a first sensor and a second according to one aspect of this disclosure.

FIG. **13**A illustrates an aspect wherein the tissue compensator is removably attached to the anvil portion of the end effector according to one aspect of this disclosure.

FIG. **13**B illustrates a detail view of a portion of the tissue compensator shown in FIG. **13**A according to one aspect of this disclosure.

FIG. **13**C illustrates various example aspects that use the layer of conductive elements and conductive elements in the staple cartridge to detect the distance between the anvil and the upper surface of the staple cartridge according to one aspect of this disclosure.

FIG. **14**A illustrates an end effector comprising conductors embedded within according to one aspect of this disclosure.

FIG. **14**B illustrates an end effector comprising conductors embedded within according to one aspect of this disclosure.

FIG. **15**A illustrates a cutaway view of the staple cartridge according to one aspect of this disclosure.

FIG. **15**B illustrates a cutaway view of the staple cartridge shown in FIG. **15**A illustrating conductors embedded within the end effector according to one aspect of this disclosure.

FIG. **16** illustrates one aspect of a left-right segmented flexible circuit for an end effector according to one aspect of this disclosure.

FIG. **17** illustrates one aspect of a segmented flexible circuit configured to fixedly attach to a jaw member of an end effector according to one aspect of this disclosure.

FIG. **18** illustrates one aspect of a segmented flexible circuit configured to mount to a jaw member of an end effector according to one aspect of this disclosure.

FIG. **19** illustrates one aspect of an end effector configured to measure a tissue gap GT according to one aspect of this disclosure.

FIG. **20** illustrates one aspect of an end effector comprising segmented flexible circuit, according to one aspect of this present disclosure.

FIG. **21** illustrates the end effector shown in FIG. **20** with the jaw member clamping tissue between the jaw member and the staple cartridge according to one aspect of this disclosure.

FIG. **22** illustrates a logic diagram of one aspect of a feedback system according to one aspect of this disclosure.

FIG. **23** illustrates a control circuit configured to control aspects of the robotic surgical system according to one aspect of this disclosure.

FIG. **24** illustrates a combinational logic circuit configured to control aspects of the robotic surgical system according to one aspect of this disclosure.

FIG. **25** illustrates a sequential logic circuit configured to control aspects of the robotic surgical system according to one aspect of this disclosure.

FIG. **26** illustrates a logic diagram of a common control module for use with a plurality of motors of the robotic surgical instrument according to one aspect of this disclosure.

FIG. **27** is a diagram of an absolute positioning system of the surgical instrument of FIG. **1** where the absolute positioning system comprises a controlled motor drive circuit arrangement comprising a sensor arrangement according to one aspect of this disclosure.

FIG. **28** is a diagram of a position sensor comprising a magnetic rotary absolute positioning system according to one aspect of this disclosure.

FIG. **29** is a section view of an end effector of the surgical instrument of FIG. **1** showing a firing member stroke relative to tissue grasped within the end effector according to one aspect of this disclosure.

FIG. **30** is a schematic diagram of a robotic surgical instrument configured to operate the surgical tool described herein according to one aspect of this disclosure.

FIG. **31** is a chart illustrating techniques for controlling the advancement or retraction velocity of a displacement member of a robotic surgical instrument according to one aspect of this disclosure.

FIG. **32** is a graphical depiction of a closed loop velocity control process according to one aspect of this disclosure.

FIG. **33** is a logic flow diagram depicting a process of a control program or a logic configuration for determining tissue conditions in an end effector and adjusting command velocity accordingly according to one aspect of this disclosure.

DESCRIPTION

Applicant of the present application owns the following patent applications filed on Jun. **29**, **2017** and which are each herein incorporated by reference in their respective entireties:

U.S. patent application Ser. No. 15/636,844, titled CLOSED LOOP VELOCITY CONTROL OF CLOSURE MEMBER FOR ROBOTIC SURGICAL INSTRUMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 29, 2017, now U.S. Pat. No. 10,398,434.

U.S. patent application Ser. No. 15/636,854, titled ROBOTIC SURGICAL INSTRUMENT WITH CLOSED LOOP FEEDBACK TECHNIQUES FOR ADVANCEMENT OF CLOSURE MEMBER DURING FIRING, by inventors Frederick E. Shelton, IV et al., filed Jun. 29, 2017, now U.S. Pat. No. 10,898,183.

U.S. patent application Ser. No. 15/636,858, titled SYSTEM FOR CONTROLLING ARTICULATION FORCES, by inventors Frederick E. Shelton, IV et al., filed Jun. 29, 2017, now U.S. Pat. No. 10,258,418.

U.S. patent application Ser. No. 15/636,829, titled CLOSED LOOP VELOCITY CONTROL TECHNIQUES FOR ROBOTIC SURGICAL INSTRUMENT, by inventors Frederick E. Shelton, IV et al., filed Jun. 29, 2017, now U.S. Pat. No. 10,932,772.

FIG. **1** depicts one aspect of a master robotic controller **11** that may be used in connection with a robotic arm slave cart **100** of the type depicted in FIG. **2**. The master controller **11** and robotic arm slave cart **100**, as well as their respective components and control systems are collectively referred to herein as a robotic surgical system **10**. Examples of such systems and devices are disclosed in U.S. Pat. No. 7,524,320, which is incorporated herein by reference. The master controller **11** generally includes master controllers (generally represented as 13 in FIG. **1**) which are grasped by the surgeon and manipulated in space while the surgeon views the procedure via a stereo display **12**. The master controllers **11** generally comprise manual input devices which preferably move with multiple degrees of freedom, and which often further have an actuatable handle for actuating tools (for example, for closing grasping saws, applying an electrical potential to an electrode, or the like). Other arrangements may provide the surgeon with a feed back meter **15** that may be viewed through the display **12** and provide the surgeon with a visual indication of the amount of force being applied to the cutting instrument or dynamic clamping member. Additional examples are disclosed in U.S. Pat. No. 9,237,891, which is incorporated herein by reference.

As can be seen in FIG. **2**, in one form, the robotic arm cart **100** is configured to actuate a plurality of surgical tools, generally designated as **200**. Various robotic surgery systems and methods employing master controller and robotic arm cart arrangements are disclosed in U.S. Pat. No. 6,132,368, entitled "Multi-Component Telepresence System and Method", the full disclosure of which is incorporated herein by reference. In various forms, the robotic arm cart **100** includes a base **102** from which, in the illustrated aspect, three surgical tools **200** are supported. In various forms, the surgical tools **200** are each supported by a series of manually articulatable linkages, generally referred to as set-up joints **104**, and a robotic manipulator **106**.

Referring now to FIG. **3**, in at least one form, robotic manipulators **106** may include a linkage **108** that constrains movement of the surgical tool **200**. In various aspects, linkage **108** includes rigid links coupled together by rotational joints in a parallelogram arrangement so that the surgical tool **200** rotates around a point in space **110**, as more fully described in issued U.S. Pat. No. 5,817,084, the full disclosure of which is herein incorporated by reference. The parallelogram arrangement constrains rotation to pivoting about an axis **112***a*, sometimes called the pitch axis. The links supporting the parallelogram linkage are pivotally mounted to set-up joints **104** (FIG. **2**) so that the surgical tool **200** further rotates about an axis **112***b*, sometimes called the yaw axis. The pitch and yaw axes **112***a*, **112***b* intersect at the remote center **114**, which is aligned along a shaft **208** of the surgical tool **200**. The surgical tool **200** may have further degrees of driven freedom as supported by manipulator **106**, including sliding motion of the surgical tool **200** along the longitudinal tool axis "LT-LT". As the surgical tool **200** slides along the tool axis LT-LT relative to manipulator **106** (arrow **112***c*), remote center **114** remains fixed relative to base **116** of manipulator **106**. Hence, the entire manipulator is generally moved to re-position remote center **114**. Linkage **108** of manipulator **106** is driven by a series of motors **120**. These motors actively move linkage **108** in response to commands from a processor of a control system. As will be discussed in further detail below, motors **120** are also employed to manipulate the surgical tool **200**.

FIG. **4** is a perspective view of a surgical tool **200** that is adapted for use with a robotic surgical system **10** that has a tool drive assembly that is operatively coupled to a master controller **11** that is operable by inputs from an operator (i.e., a surgeon) is depicted in FIG. **4**. As can be seen in that Figure, the surgical tool **200** includes a surgical end effector **1012** that comprises an endocutter. In at least one form, the surgical tool **200** generally includes an elongated shaft assembly **1008** that has a proximal closure tube **1040** and a distal closure tube **1042** that are coupled together by an articulation joint **1011**. The surgical tool **200** is operably coupled to the manipulator by a tool mounting portion, generally designated as **300**. The surgical tool **200** further includes an interface **230** which mechanically and electrically couples the tool mounting portion **300** to the manipulator. In various aspects, the tool mounting portion **300** includes a tool mounting plate **302** that operably supports a plurality of (four are shown in FIG. **6**) rotatable body portions, driven discs or elements **304**, that each include a pair of pins **306** that extend from a surface of the driven element **304**. One pin **306** is closer to an axis of rotation of each driven elements **304** than the other pin **306** on the same driven element **304**, which helps to ensure positive angular alignment of the driven element **304**. Interface **230** includes an adaptor portion **240** that is configured to mountingly engage the mounting plate **302** as will be further discussed below. The adaptor portion **240** may include an array of electrical connecting pins which may be coupled to a memory structure by a circuit board within the tool mounting portion **300**. While interface **230** is described herein with reference to mechanical, electrical, and magnetic coupling elements, it should be understood that a wide variety of telemetry modalities might be used, including infrared, inductive coupling, or the like.

FIG. **5** is an exploded assembly view of an adapter and tool holder arrangement for attaching various surgical tools according to one aspect of this disclosure. A detachable latch arrangement **239** may be employed to releasably affix the adaptor **240** to the tool holder **270**. As used herein, the term "tool drive assembly" when used in the context of the robotic surgical system **10**, at least encompasses various aspects of the adapter **240** and tool holder **270** and which has been generally designated as **101** in FIG. **5**. For example, as can be seen in FIG. **5**, the tool holder **270** may include a first latch pin arrangement **274** that is sized to be received in corresponding clevis slots **241** provided in the adaptor **240**. In addition, the tool holder **270** may further have second latch pins **276** that are sized to be retained in corresponding latch devises in the adaptor **240**. In at least one form, a latch assembly **245** is movably supported on the adapter **240** and is biasable between a first latched position wherein the latch pins **276** are retained within their respective latch clevis and an unlatched position wherein the second latch pins **276** may be into or removed from the latch devises. A spring or springs (not shown) are employed to bias the latch assembly into the latched position. A lip on the tool side **244** of adaptor **240** may slidably receive laterally extending tabs of tool mounting housing **301**. The adaptor portion **240** may include an array of electrical connecting pins **242** which may be coupled to a memory structure by a circuit board within the tool mounting portion **300**. While interface **230** is described herein with reference to mechanical, electrical, and magnetic coupling elements, it should be understood that a wide variety of telemetry modalities might be used, including infrared, inductive coupling, or the like.

As shown in FIGS. **4-6** the adapter portion **240** generally includes a tool side **244** and a holder side **246**. In various forms, a plurality of rotatable bodies **250** are mounted to a floating plate **248** which has a limited range of movement relative to the surrounding adaptor structure normal to the major surfaces of the adaptor **240**. Axial movement of the floating plate **248** helps decouple the rotatable bodies **250** from the tool mounting portion **300** when the levers **303** along the sides of the tool mounting portion housing **301** are actuated. Other mechanisms/arrangements may be employed for releasably coupling the tool mounting portion **300** to the adaptor **240**. In at least one form, rotatable bodies **250** are resiliently mounted to floating plate **248** by resilient radial members which extend into a circumferential indentation about the rotatable bodies **250**. The rotatable bodies **250** can move axially relative to plate **248** by deflection of these resilient structures. When disposed in a first axial position (toward tool side **244**) the rotatable bodies **250** are free to rotate without angular limitation. However, as the rotatable bodies **250** move axially toward tool side **244**, tabs **252** (extending radially from the rotatable bodies **250**) laterally engage detents on the floating plates so as to limit angular rotation of the rotatable bodies **250** about their axes. This limited rotation can be used to help drivingly engage the rotatable bodies **250** with drive pins **272** of a corresponding tool holder portion **270** of the robotic system **10**, as the drive pins **272** will push the rotatable bodies **250** into the limited rotation position until the pins **11234** are aligned with (and slide into) openings **256'**. Openings **256** on the tool side **244** and openings **256'** on the holder side **246** of rotatable bodies **250** are configured to accurately align the driven elements **304** of the tool mounting portion **300** with the drive elements **271** of the tool holder **270**. As described above regarding inner and outer pins **306** of driven elements **304**, the openings **256**, **256'** are at differing distances from the axis of rotation on their respective rotatable bodies **250** so as to ensure that the alignment is not 180 degrees from its intended position. Additionally, each of the openings **256** is slightly radially elongated so as to fittingly receive the pins **306** in the circumferential orientation. This allows the pins **306** to slide radially within the openings **256**, **256'** and accommodate some axial misalignment between the tool **200** and tool holder **270**, while minimizing any angular misalignment and backlash between the drive and driven elements. Openings **256** on the tool side **244** are offset by about 90 degrees from the openings **256'** (shown in broken lines) on the holder side **246**.

FIG. **6** is a partial bottom perspective view of the surgical tool aspect of FIG. **4**. As shown in FIGS. **6-10**, the surgical end effector **1012** is attached to the tool mounting portion **300** by an elongated shaft assembly **1008** according to various aspects. As shown in the illustrated aspect, the shaft assembly **1008** includes an articulation joint generally indicated as **1011** that enables the surgical end effector **1012** to be selectively articulated about an articulation axis AA-AA that is substantially transverse to a longitudinal tool axis LT-LT. See FIG. **7**. In other aspects, the articulation joint is omitted. In various aspects, the shaft assembly **1008** may include a closure tube assembly **1009** that comprises a proximal closure tube **1040** and a distal closure tube **1042** that are pivotably linked by a pivot links **1044** and operably supported on a spine assembly generally depicted as **1049**. In the illustrated aspect, the spine assembly **1049** comprises a distal spine portion **1050** that is attached to the elongated channel **1022** and is pivotally coupled to the proximal spine portion **1052**. The closure tube assembly **1009** is configured to axially slide on the spine assembly **1049** in response to actuation motions applied thereto. The distal closure tube **1042** includes an opening **1045** into which the tab **1027** on the anvil **1024** is inserted in order to facilitate opening of the anvil **1024** as the distal closure tube **1042** is moved axially in the proximal direction "PD". The closure tubes **1040**, **1042** may be made of electrically conductive material (such as metal) so that they may serve as part of the antenna, as described above. Components of the main drive shaft assembly (e.g., the drive shafts **1048**, **1050**) may be made of a nonconductive material (such as plastic). The anvil **1024** may be pivotably opened and closed at a pivot point **1025** located at the proximal end of the elongated channel **1022**.

In use, it may be desirable to rotate the surgical end effector **1012** about the longitudinal tool axis LT-LT. In at least one aspect, the tool mounting portion **300** includes a rotational transmission assembly **1069** that is configured to receive a corresponding rotary output motion from the tool drive assembly **101** of the robotic surgical system **10** and convert that rotary output motion to a rotary control motion for rotating the elongated shaft assembly **1008** (and surgical end effector **1012**) about the longitudinal tool axis LT-LT. In various aspects, for example, the proximal end **1060** of the proximal closure tube **1040** is rotatably supported on the tool mounting plate **302** of the tool mounting portion **300** by a forward support cradle **309** and a closure sled **1100** that is also movably supported on the tool mounting plate **302**. In at least one form, the rotational transmission assembly **1069** includes a tube gear segment **1062** that is formed on (or attached to) the proximal end **1060** of the proximal closure tube **1040** for operable engagement by a rotational gear assembly **1070** that is operably supported on the tool mounting plate **302**. As shown in FIG. **8**, the rotational gear assembly **1070**, in at least one aspect, comprises a rotation drive gear **1072** that is coupled to a corresponding first one of the driven discs or elements **304** on the adapter side **307** of the tool mounting plate **302** when the tool mounting portion **300** is coupled to the tool drive assembly **101**. See FIG. **6**. The rotational gear assembly **1070** further comprises a rotary driven gear **1074** that is rotatably supported on the tool mounting plate **302** in meshing engagement with the tube gear segment **1062** and the rotation drive gear **1072**. Application of a first rotary output motion from the tool drive assembly **101** of the robotic surgical system **10** to the corresponding driven element **304** will thereby cause rotation of the rotation drive gear **1072**. Rotation of the rotation drive gear **1072** ultimately results in the rotation of the elongated shaft assembly **1008** (and the surgical end effector **1012**) about the longitudinal tool axis LT-LT (represented by arrow "R" in FIG. **8**). It will be appreciated that the application of a rotary output motion from the tool drive assembly **101** in one direction will result in the rotation of the elongated shaft assembly **1008** and surgical end effector **1012** about the longitudinal tool axis LT-LT in a first direction and an application of the rotary output motion in an opposite direction will result in the rotation of the elongated shaft assembly **1008** and surgical end effector **1012** in a second direction that is opposite to the first direction.

In at least one aspect, the closure of the anvil **1024** relative to the staple cartridge **1034** is accomplished by axially moving the closure tube assembly **1009** in the distal direction "DD" on the spine assembly **1049**. As indicated above, in various aspects, the proximal end **1060** of the proximal closure tube **1040** is supported by the closure sled **1100** which comprises a portion of a closure transmission, generally depicted as **1099**. In at least one form, the closure sled **1100** is configured to support the closure tube **1009** on the tool mounting plate **320** such that the proximal closure tube **1040** can rotate relative to the closure sled **1100**, yet travel axially with the closure sled **1100**. In particular, the closure sled **1100** has an upstanding tab **1101** that extends into a radial groove **1063** in the proximal end portion of the proximal closure tube **1040**. In addition, as can be seen in FIG. **10**, the closure sled **1100** has a tab portion **1102** that extends through a slot **305** in the tool mounting plate **302**. The tab portion **1102** is configured to retain the closure sled **1100** in sliding engagement with the tool mounting plate **302**. In various aspects, the closure sled **1100** has an upstanding portion **1104** that has a closure rack gear **1106** formed thereon. The closure rack gear **1106** is configured for driving engagement with a closure gear assembly **1110**. The knife rack gear **1106** is slidably supported within a rack housing **1210** that is attached to the tool mounting plate **302** such that the knife rack gear **1106** is retained in meshing engagement with a knife gear assembly **1220**.

In various forms, the closure gear assembly **1110** includes a closure spur gear **1112** that is coupled to a corresponding second one of the driven discs or elements **304** on the adapter side **307** of the tool mounting plate **302**. See FIG. **6**. Thus, application of a second rotary output motion from the tool drive assembly **101** of the robotic surgical system **10** to the corresponding second driven element **304** will cause rotation of the closure spur gear **1112** when the tool mounting portion **300** is coupled to the tool drive assembly **101**. The closure gear assembly **1110** further includes a closure reduction gear set **1114** that is supported in meshing engagement with the closure spur gear **1112**. As can be seen in FIGS. **9** and **10**, the closure reduction gear set **1114** includes a driven gear **1116** that is rotatably supported in meshing engagement with the closure spur gear **1112**. The closure reduction gear set **1114** further includes a first closure drive gear **1118** that is in meshing engagement with a second closure drive gear **1120** that is rotatably supported on the tool mounting plate **302** in meshing engagement with the closure rack gear **1106**. Thus, application of a second rotary output motion from the tool drive assembly **101** of the robotic surgical system **10** to the corresponding second driven element **11304** will cause rotation of the closure spur gear **1112** and the closure transmission **1110** and ultimately drive the closure sled **1100** and closure tube assembly **1009** axially. The axial direction in which the closure tube assembly **1009** moves ultimately depends upon the direction in which the second driven element **304** is rotated. For example, in response to one rotary output motion received from the tool drive assembly **101** of the robotic surgical system **10**, the closure sled **1100** will be driven in the distal direction "DD" and ultimately drive the closure tube assembly **101** in the distal direction. As the distal closure tube **1042** is driven distally, the end of the closure tube segment **1042** will engage a portion of the anvil **1024** and cause the anvil **1024** to pivot to a closed position. Upon application of an "opening" out put motion from the tool drive assembly **101** of the robotic surgical system **10**, the closure sled **1100** and shaft assembly **1008** will be driven in the proximal direction "PD". As the distal closure tube **1042** is driven in the proximal direction, the opening **1045** therein interacts with the tab **1027** on the anvil **1024** to facilitate the opening thereof. In various aspects, a spring (not shown) may be employed to bias the anvil to the open position when the distal closure tube **1042** has been moved to its starting position. In various aspects, the various gears of the closure gear assembly **1110** are sized to generate the necessary closure forces needed to satisfactorily close the anvil **1024** onto the tissue to be cut and stapled by the surgical end effector **1012**. For example, the gears of the closure transmission **1110** may be sized to generate approximately 70-120 pounds.

FIG. **11**A is a partial cross-sectional side view of the surgical tool **200** of FIG. **6** and FIG. **11**B is an enlarged cross-sectional view of a portion of the surgical tool depicted in FIG. **11**A according to one aspect of this disclosure. With reference to FIGS. **11**A and **11**B, the distal end **1202** of the knife bar **1200** is attached to the cutting instrument **1032**. The proximal end **1204** of the knife bar **1200** is rotatably affixed to a knife rack gear **1206** such that the knife bar **1200** is free to rotate relative to the knife rack gear **1206**. The knife rack gear **1206** is slidably supported within a rack housing **1210** that is attached to the tool mounting plate **302** such that the knife rack gear **1206** is retained in meshing engagement with a knife gear assembly **1220**. More specifically and with reference to FIG. **10**, in at least one aspect, the knife gear assembly **1220** includes a knife spur gear **1222** that is coupled to a corresponding third one of the driven discs or elements **304** on the adapter side **307** of the tool mounting plate **302**. See FIG. **6**. Thus, application of another rotary output motion from the robotic system **10** through the tool drive assembly **101** to the corresponding third driven element **304** will cause rotation of the knife spur gear **1222**. The knife gear assembly **1220** further includes a knife gear reduction set **1224** that includes a first knife drive gear **1226** and a second knife drive gear **1228**. The knife gear reduction set **1224** is rotatably mounted to the tool mounting plate **302** such that the first knife drive gear **1226** is in meshing engagement with the knife spur gear **1222**. Likewise, the second knife drive gear **1228** is in meshing engagement with a third knife drive gear **1230** that is rotatably supported on the tool mounting plate **302** in meshing engagement with the knife rack gear **1206**. In various aspects, the gears of the knife gear assembly **1220** are sized to generate the forces needed to drive the cutting element **1032** through the tissue clamped in the surgical end effector **1012** and actuate the staples therein. For example, the gears of the knife drive assembly **1230** may be sized to generate approximately 40 to 100 pounds. It will be appreciated that the application of a rotary output motion from the tool drive assembly **101** in one direction will result in the axial movement of the cutting instrument **1032** in a distal direction and application of the rotary output motion in an opposite direction will result in the axial travel of the cutting instrument **1032** in a proximal direction.

In various aspects, the surgical tool **200** employs an articulation system that includes an articulation joint **12011** that enables the surgical end effector **1012** to be articulated about an articulation axis AA-AA that is substantially transverse to the longitudinal tool axis LT-LT. In at least one aspect, the surgical tool **200** includes first and second articulation bars **1250***a*, **1250***b* that are slidably supported within corresponding passages provided through the proximal spine portion **1052**. In at least one form, the first and second articulation bars **1250***a*, **1250***b* are actuated by an articulation transmission that is operably supported on the tool mounting plate **302**. Each of the articulation bars **1250***a*, **1250***b* has a proximal end that has a guide rod protruding therefrom which extend laterally through a corresponding slot in the proximal end portion of the proximal spine portion and into a corresponding arcuate slot in an articulation nut **1260** which comprises a portion of the articulation transmission. The articulation bar **1250***a* has a guide rod **1254** which extends laterally through a corresponding slot in the proximal end portion of the distal spine portion **1050** and into a corresponding arcuate slot in the articulation nut **1260**. In addition, the articulation bar **1250***a* has a distal end that is pivotally coupled to the distal spine portion **1050** by, for example, a pin and articulation bar **1250***b* has a distal end that is pivotally coupled to the distal spine portion **1050** by a pin. In particular, the articulation bar **1250***a* is laterally offset in a first lateral direction from the longitudinal tool axis LT-LT and the articulation bar **1250***b* is laterally offset in a second lateral direction from the longitudinal tool axis LT-LT. Thus, axial movement of the articulation bars **1250***a*, **1250***b* in opposing directions will result in the articulation of the distal spine portion **1050** as well as the surgical end effector **1012** attached thereto about the articulation axis AA-AA as will be discussed in further detail below.

Articulation of the surgical end effector **1012** is controlled by rotating the articulation nut **1260** about the longitudinal tool axis LT-LT. The articulation nut **1260** is rotatably journaled on the proximal end portion of the distal spine portion **1050** and is rotatably driven thereon by an articulation gear assembly **1270**. More specifically and with reference to FIG. **8**, in at least one aspect, the articulation gear assembly **1270** includes an articulation spur gear **1272** that is coupled to a corresponding fourth one of the driven discs or elements **304** on the adapter side **307** of the tool mounting plate **302**. Thus, application of another rotary input motion from the robotic system **10** through the tool drive assembly **101** to the corresponding fourth driven element **304** will cause rotation of the articulation spur gear **1272** when the interface **230** is coupled to the tool holder **270**. An articulation drive gear **1274** is rotatably supported on the tool mounting plate **302** in meshing engagement with the articulation spur gear **1272** and a gear portion **1264** of the articulation nut **1260** as shown. The articulation nut **1260** has a shoulder **1266** formed thereon that defines an annular groove **1267** for receiving retaining posts **1268** therein. Retaining posts **1268** are attached to the tool mounting plate **302** and serve to prevent the articulation nut **1260** from moving axially on the proximal spine portion **1052** while maintaining the ability to be rotated relative thereto. Thus, rotation of the articulation nut **1260** in a first direction, will result in the axial movement of the articulation bar **1250***a* in a distal direction "DD" and the axial movement of the articulation bar **1250***b* in a proximal direction "PD" because of the interaction of the guide rods **1254** with the spiral slots in the articulation gear **1260**. Similarly, rotation of the articulation nut **1260** in a second direction that is opposite to the first direction will result in the axial movement of the articulation bar **1250***a* in the proximal direction "PD" as well as cause articulation bar **1250***b* to axially move in the distal direction "DD". Thus, the surgical end effector **1012** may be selectively articulated about articulation axis "AA-AA" in a first direction "FD" by simultaneously moving the articulation bar **1250***a* in the distal direction "DD" and the articulation bar **1250***b* in the proximal direction "PD". Likewise, the surgical end effector **1012** may be selectively articulated about the articulation axis "AA-AA" in a second direction "SD" by simultaneously moving the articulation bar **1250***a* in the proximal direction "PD" and the articulation bar **1250***b* in the distal direction "DD."

The tool aspect described above employs an interface arrangement that is particularly well-suited for mounting the robotically controllable medical tool onto at least one form of robotic arm arrangement that generates at least four different rotary control motions. Those of ordinary skill in the art will appreciate that such rotary output motions may be selectively controlled through the programmable control systems employed by the robotic system/controller. For example, the tool arrangement described above may be well-suited for use with those robotic systems manufactured by Intuitive Surgical, Inc. of Sunnyvale, Calif., U.S.A., many of which may be described in detail in various patents incorporated herein by reference. The unique and novel aspects of various aspects of the present invention serve to utilize the rotary output motions supplied by the robotic system to generate specific control motions having sufficient magnitudes that enable end effectors to cut and staple tissue. Thus, the unique arrangements and principles of various aspects of the present invention may enable a variety of different forms of the tool systems disclosed and claimed herein to be effectively employed in connection with other types and forms of robotic systems that supply programmed rotary or other output motions. In addition, as will become further apparent as the present Detailed Description proceeds, various end effector aspects of the present invention that require other forms of actuation motions may also be effectively actuated utilizing one or more of the control motions generated by the robotic system.

FIG. **12** illustrates one aspect of an end effector **3000** comprising a first sensor **3008***a* and a second sensor **3008***b*. The first and second sensors **3008***a*, **3008***b* are provided on the cartridge deck to determine tissue location using segmented electrodes. Accordingly, the first and second sensors **3008***a*, **3008***b* enable sensing the load on the closure tube, the position of the closure tube, the firing member at the rack and the position of the firing member coupled to the I-beam **3005**, the portion of the cartridge that contains tissue, the load and position on the articulation rods. The end effector **3000** comprises a first jaw member, or anvil, **3002** pivotally coupled to a second jaw member **3004**. The second jaw member **3004** is configured to receive a staple cartridge **3006** therein. The staple cartridge **3006** comprises a plurality of staples. The plurality of staples is deployable from the staple cartridge **3006** during a surgical operation. The end effector **3000** comprises a first sensor **3008***a*. The first sensor **3008***a* is configured to measure one or more parameters of the end effector **3000**. For example, in one aspect, the first sensor **3008***a* is configured to measure the gap **3010** between the anvil **3002** and the second jaw member **3004**. The first sensor **3008***a* may comprise, for example, a Hall effect sensor configured to detect a magnetic field generated by a magnet **3012** embedded in the second jaw member **3004** and/or the staple cartridge **3006**. As another example, in one aspect, the first sensor **3008***a* is configured to measure one or more forces exerted on the anvil **3002** by the second jaw member **3004** and/or tissue clamped between the anvil **3002** and the second jaw member **3004**. The sensors **3008***a*, **3008***b* may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within the end effector **3000**.

The end effector **3000** comprises a second sensor **3008***b*. The second sensor **3008***b* is configured to measure one or more parameters of the end effector **3000**. For example, in various aspects, the second sensor **3008***b* may comprise a strain gauge configured to measure the magnitude of the strain in the anvil **3002** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. In various aspects, the first sensor **3008***a* and/or the second sensor **3008***b* may comprise, for example, a magnetic sensor such as, for example, a Hall effect sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as, for example, an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **3000**. The first sensor **3008***a* and the second sensor **3008***b* may be arranged in a series configuration and/or a parallel configuration. In a series configuration, the second sensor **3008***b* may be configured to directly affect the output of the first sensor **3008***a*. In a parallel configuration, the second sensor **3008***b* may be configured to indirectly affect the output of the first sensor **3008***a*.

In one aspect, the first sensor **3008***a* may be configured to measure the gap **3010** between the anvil **3002** and the second jaw member **3004**. The gap **3010** is representative of the thickness and/or compressibility of a tissue section clamped between the anvil **3002** and the staple cartridge **3006**. The first sensor **3008***a* may comprise, for example, a Hall effect sensor configured to detect a magnetic field generated by a magnet **3012** coupled to the second jaw member **3004** and/or the staple cartridge **3006**. Measuring at a single location accurately describes the compressed tissue thickness for a calibrated full bit of tissue, but may provide inaccurate results when a partial bite of tissue is placed between the anvil **3002** and the second jaw member **3004**. A partial bite of tissue, either a proximal partial bite or a distal partial bite, changes the clamping geometry of the anvil **3002**.

In some aspects, the second sensor **3008***b* may be configured to detect one or more parameters indicative of a type of tissue bite, for example, a full bite, a partial proximal bite, and/or a partial distal bite. In some aspects, the thickness measurement of the first sensor **3008***a* may be provided to an output device of the robotic surgical system **10** coupled to the end effector **3000**. For example, in one aspect, the end effector **3000** is coupled to the robotic surgical system **10** comprising a display. The measurement of the first sensor **3008***a* is provided to a processor.

In another aspect, the end effector **3000** may comprise a plurality of second sensors configured to measure an amplitude of strain exerted on the anvil **3002** during a clamping procedure. In another aspect, the plurality of sensors allows a robust tissue thickness sensing process to be implemented. By detecting various parameters along the length of the anvil **3202**, the plurality of sensors allow a surgical instrument, such as, for example, the surgical instrument **10**, to calculate the tissue thickness in the jaws regardless of the bite, for example, a partial or full bite. In some aspects, the plurality of sensors comprises a plurality of strain gauges. The plurality of strain gauges is configured to measure the strain at various points on the anvil **3002**. The amplitude and/or the slope of the strain at each of the various points on the anvil **3002** can be used to determine the thickness of tissue in between the anvil **3002** and the staple cartridge **3006**. The plurality of strain gauges may be configured to optimize maximum amplitude and/or slope differences based on clamping dynamics to determine thickness, tissue placement, and/or material properties of the tissue. Time based monitoring of the plurality of sensors during clamping allows a processor, such as, for example, a primary processor, to utilize algorithms and look-up tables to recognize tissue characteristics and clamping positions and dynamically adjust the end effector **3000** and/or tissue clamped between the anvil **3002** and the staple cartridge **3006**.

FIG. **13**A illustrates an aspect of an end effector **5500** comprising a layer of conductive elements **5512**. The end effector **5500** is similar to the end effector **3000** described above. The end effector **5500** comprises a first jaw member, or anvil, **5502** pivotally coupled to a second jaw member **5504**. The second jaw member **5504** is configured to receive a staple cartridge **5506** therein. FIG. **13**B illustrates a detail view of a portion of the tissue compensator shown in FIG. **13**A. The conductive elements **5512** can comprise any combination of conductive materials in any number of configurations, such as for instance coils of wire, a mesh or grid of wires, conductive strips, conductive plates, electrical circuits, microprocessors, or any combination thereof. The layer containing conductive elements **5512** can be located on the anvil-facing surface **5514** of the tissue compensator **5510**. Alternatively or additionally, the layer of conductive elements **5512** can be located on the staple cartridge-facing surface **5516** of the tissue compensator **5510**. The conductive elements **5512** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within the end effector **5500**. Additional examples are disclosed in Patent Application No. US 2016/0066912, which is incorporated herein by reference.

FIG. **13**C illustrates various example aspects that use the layer of conductive elements **5512** and conductive elements **5524**, **5526**, and **5528** in the staple cartridge **5506** to detect the distance between the anvil **5502** and the upper surface of the staple cartridge **5506**. The distance between the anvil **5502** and the staple cartridge **5506** indicates the amount and/or density of tissue **5518** compressed therebetween. This distance can additionally or alternatively indicate which areas of the end effector **5500** contain tissue. The tissue **5518** thickness, density, and/or location can be communicated to the operator of the surgical instrument **10**.

In the illustrated example aspects, the layer of conductive elements **5512** is located on the anvil-facing surface **5514** of the tissue compensator **5510**, and comprises one or more coils of wire **5522** in communication with a control circuit comprising a microprocessor **5520**. The microprocessor **5500** can be located in the end effector **5500** or any component thereof, or can be located in the tool mounting housing **301** of the instrument, or can comprise any microprocessor or microcontroller previously described. In the illustrated example aspects, the staple cartridge **5506** also includes conductive elements, which can be any one of: one or more coils of wire **5524**, one or more conductive plates **5526**, a mesh of wires **5528**, or any other convenient configuration, or any combination thereof. The conductive elements of the staple cartridge **5506** can be in communication with the same microprocessor **5520** or some other microprocessor in the robotic surgical instrument. The conductive elements **5512** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within the end effector **5500**.

When the anvil **5502** is in a closed position and thus is compressing tissue **5518** against staple cartridge **5506**, the layer of conductive elements **5512** of the tissue compensator **5510** can capacitively couple with the conductors in staple cartridge **5506**. The strength of the capacitive field between the layer of conductive elements **5512** and the conductive elements of the staple cartridge **5506** can be used to determine the amount of tissue **5518** being compressed. Alternatively, the staple cartridge **5506** can comprise eddy current sensors in communication with a microprocessor **5520**, wherein the eddy current sensors are operable to sense the distance between the anvil **5502** and the upper surface of the staple cartridge **5506** using eddy currents.

It is understood that other configurations of conductive elements are possible, and that the aspects of FIG. **13**C are by way of example only, and not limitation. For example, in some aspects the layer of conductive elements **5512** can be located on the staple cartridge-facing surface **5516** of the tissue compensator **5510**. Also, in some aspects the conductive elements **5524**, **5526**, and/or **5528** can be located on or within the anvil **5502**. Thus in some aspects, the layer of conductive elements **5512** can capacitively couple with conductive elements in the anvil **5502** and thereby sense properties of tissue **5518** enclosed within the end effector.

It can also be recognized that a layer of conductive elements **5512** may be disposed on both the anvil-facing surface **5514** and the cartridge-facing surface **5516**. A system to detect the amount, density, and/or location of tissue **5518** compressed by the anvil **5502** against the staple cartridge **5506** can comprise conductors or sensors either in the anvil **5502**, the staple cartridge **5506**, or both. Aspects that include conductors or sensors in both the anvil **5502** and the staple cartridge **5506** can optionally achieve enhanced results by allowing differential analysis of the signals that can be achieved by this configuration.

Turning now to FIG. **14**A, there is illustrated a close-up cutaway view of the end effector **5600** with the anvil **5602** in a closed position. FIG. **14**B illustrates the end effector **5600** comprising electrical conductors **5620** embedded within according to one aspect of this disclosure. In a closed position, the anvil **5602** can compress tissue **5618** between the tissue compensator **5610** and the staple cartridge **5606**. In some cases, only a part of the end effector **5600** may be enclosing the tissue **5618**. In areas of the end effector **5600** that are enclosing tissue **5618**, in areas of greater compression **5624**, the array of conductors **5620** will also be compressed, while in uncompressed **5626** areas, the array of conductors **5620** will be further apart. Hence, the conductivity, resistance, capacitance, and/or some other electrical property between the array of conductors **5620** can indicate which areas of the end effector **5600** contain tissue. The array of conductors **5620** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within the end effector **5600**.

With reference to FIGS. **14**A and **14**B, the end effector **5600** comprising a tissue compensator **5610** further comprising conductors **5620** embedded within. The end effector **5600** comprises a first jaw member, or anvil **5602** pivotally coupled to a second jaw member **5604**. The second jaw member **5604** is configured to receive a staple cartridge **5606** therein. In some aspects, the end effector **5600** further comprises a tissue compensator **5610** removably positioned on the anvil **5602** or the staple cartridge **5606**.

An array of conductors **5620** are embedded within the material that comprises the tissue compensator **5610**. The array of conductors **5620** can be arranged in an opposing configuration, and the opposing elements can be separated by insulating material. The array of conductors **5620** are each coupled to one or more conductive wires **5622**. The conductive wires **5622** allow the array of conductors **5620** to communicate with a microprocessor or control circuit **961** (FIG. **22**), **800** (FIG. **23**), **810** (FIG. **24**), **820** (FIG. **25**), **4420** (FIG. **26**), **2510** (FIG. **30**). The array of conductors **5620** may span the width of the tissue compensator **5610** such that they will be in the path of a cutting member or knife bar **280**. As the knife bar **280** advances, it will sever, destroy, or otherwise disable the conductors **5620**, and thereby indicate its position within the end effector **5600**. The array of conductors **5610** can comprise conductive elements, electric circuits, microprocessors, or any combination thereof.

FIGS. **15**A and **15**B illustrate an aspect of an end effector **5650** further comprising conductors **5662** embedded therein. The end effector **5650** comprises a first jaw member, or anvil, **5652** pivotally coupled to a second jaw member **5654**. The second jaw member **5654** is configured to receive a staple cartridge **5656** therein. FIG. **15**A illustrates a cutaway view of the staple cartridge **5656**. The cutaway view illustrates conductors **5670** embedded within the end effector. Each of the conductors **5672** is coupled to a conductive wire **5672**. The conductive wires **5672** allow the array of conductors **5672** to communicate with a microprocessor. The conductors **5672** may comprise conductive elements, electric circuits, microprocessors, or any combination thereof. FIG. **15**B illustrates a close-up side view of the end effector **5650** with the anvil **5652** in a closed position. In a closed position, the anvil **5652** can compress tissue **5658** against the staple cartridge **5656**. The conductors **5672** embedded within the tissue compensator **5660** can be operable to apply pulses of electrical current **5674**, at predetermined frequencies, to the tissue **5658**. The same or additional conductors **5672** can detect the response of the tissue **5658** and transmit this response to a microprocessor or microcontroller located in the instrument. The response of the tissue **5658** to the electrical pulses **5674** can be used to determine a property of the tissue **5658**. For example, the galvanic response of the tissue **5658** indicates the moisture content in the tissue **5658**. As another example, measurement of the electrical impedance through the tissue **5658** could be used to determine the conductivity of the tissue **5648**, which is an indicator of the tissue type. Other properties that can be determined include by way of example and not limitation: oxygen content, salinity, density, and/or the presence of certain chemicals. By combining data from several sensors, other properties could be determined, such as blood flow, blood type, the presence of antibodies, etc. The conductors **5662** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within the end effector **5650**.

FIG. **16** illustrates one aspect of a left-right segmented flexible circuit **4600**. The left-right segmented flexible circuit **4600** comprises a plurality of segments L**1**-L**5** on the left side of the left-right segmented flexible circuit **4600** and a plurality of segments R**1**-R**5** on the right side of the left-right segmented flexible circuit **4600**. Each of the segments L**1**-L**5** and R**1**-R**5** comprise temperature sensors and/or force sensors to sense tissue parameters locally within each segment L**1**-L**5** and R**1**-R**5**. The left-right segmented flexible circuit **4600** is configured to sense tissue parameters locally within each of the segments L**1**-L**5** and R**1**-R**5**. The flexible circuit **4600** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within an end effector.

FIG. **17** illustrates one aspect of a segmented flexible circuit **6430** configured to fixedly attach to a jaw member **6434** of an end effector. The segmented flexible circuit **6430** comprises a distal segment **6432***a* and lateral segments **6432***b*, **6432***c* that include individually addressable sensors to provide local tissue presence detection. The segments **6432***a*, **6432***b*, **6432***c* are individually addressable to detect tissue and to measure tissue parameters based on individual sensors located within each of the segments **6432***a*, **6432***b*, **6432***c*. The segments **6432***a*, **6432***b*, **6432***c* of the segmented flexible circuit **6430** are mounted to the jaw member **6434** and are electrically coupled to an energy source such as an electrical circuit via electrical conductive elements **6436**. A Hall effect sensor **6438**, or any suitable magnetic sensor, is located on a distal end of the jaw member **6434**. The Hall effect sensor **6438** operates in conjunction with a magnet to provide a measurement of an aperture defined by the jaw member **6434**, which otherwise may be referred to as a tissue gap, as shown with particularity in FIG. **19**. The segmented flexible circuit **6430** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within an end effector.

FIG. **18** illustrates one aspect of a segmented flexible circuit **6440** configured to mount to a jaw member **6444** of an end effector. The segmented flexible circuit **6580** comprises a distal segment **6442***a* and lateral segments **6442***b*, **6442***c* that include individually addressable sensors for tissue control. The segments **6442***a*, **6442***b*, **6442***c* are individually addressable to treat tissue and to read individual sensors located within each of the segments **6442***a*, **6442***b*, **6442***c*. The segments **6442***a*, **6442***b*, **6442***c* of the segmented flexible circuit **6440** are mounted to the jaw member **6444** and are electrically coupled to an energy source, via electrical conductive elements **6446**. A Hall effect sensor **6448**, or other suitable magnetic sensor, is provided on a distal end of the jaw member **6444**. The Hall effect sensor **6448** operates in conjunction with a magnet to provide a measurement of an aperture defined by the jaw member **6444** of the end effector or tissue gap as shown with particularity in FIG. **19**. In addition, a plurality of lateral asymmetric temperature sensors **6450***a*, **6450***b* are mounted on or formally integrally with the segmented flexible circuit **6440** to provide tissue temperature feedback to the control circuit. The segmented flexible circuit **6440** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within an end effector.

FIG. **19** illustrates one aspect of an end effector **6460** configured to measure a tissue gap G_T. The end effector **6460** comprises a jaw member **6462** and a jaw member **6444**. The flexible circuit **6440** as described in FIG. **18** is mounted to the jaw member **6444**. The flexible circuit **6440** comprises a Hall effect sensor **6448** that operates with a magnet **6464** mounted to the jaw member **6462** to measure the tissue gap G_T. This technique can be employed to measure the aperture defined between the jaw member **6444** and the jaw member **6462**. The jaw member **6462** may be a staple cartridge.

FIG. **20** illustrates one aspect of an end effector **6470** comprising segmented flexible circuit **6468** as shown in FIG. **16**. The end effector **6470** comprises a jaw member **6472** and a staple cartridge **6474**. The segmented flexible circuit **6468** is mounted to the jaw member **6472**. Each of the sensors disposed within the segments **1-5** are configured to detect the presence of tissue positioned between the jaw member **6472** and the staple cartridge **6474** and represent tissue zones **1-5**. In the configuration shown in FIG. **20**, the end effector **6470** is shown in an open position ready to receive or grasp tissue between the jaw member **6472** and the staple cartridge **6474**. The segmented flexible circuit **6468** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within the end effector **6470**.

FIG. **21** illustrates the end effector **6470** shown in FIG. **20** with the jaw member **6472** clamping tissue **6476** between the jaw members **6472**, e.g., the anvil and the staple cartridge. As shown in FIG. **21**, the tissue **6476** is positioned between segments **1-3** and represents tissue zones **1-3**. Accordingly, tissue **6476** is detected by the sensors in segments **1-3** and the absence of tissue (empty) is detected in section **6478** by segments **4-5**. The information regarding the presence and absence of tissue **6476** positioned within certain segments **1-3** and **4-5**, respectively, is communicated to a control circuit as described herein via interface circuits, for example. The control circuit is configured to detect tissue located in segments **1-3**. It will be appreciated that the segments **1-5** may contain any suitable temperature, force/pressure, and/or Hall effect magnetic sensors to measure tissue parameters of tissue located within certain segments **1-5** and electrodes to deliver energy to tissue located in certain segments **1-5**. The segmented flexible circuit **6468** may be employed to measure tissue thickness, force, displacement, compression, tissue impedance, and tissue location within the end effector **6470**.

FIG. **22** illustrates a logic diagram of a feedback system **970** of the robotic surgical system **10** of FIG. **1** in accordance with one or more aspects of the present disclosure. The system **970** comprises a circuit. The circuit includes a controller **961** comprising a processor **962** and a memory **968**. One or more of sensors **972**, **974**, **976**, such as, for example, provide real time feedback to the processor **962**. A motor **982** driven by a motor driver **992** operably couples a longitudinally movable displacement member to drive the I-beam knife element. A tracking system **980** is configured to determine the position of the longitudinally movable displacement member. The position information is provided to the processor **962**, which can be programmed or configured to determine the position of the longitudinally movable drive member as well as the position of a firing member, firing bar, and I-beam knife element. Additional motors may be provided at the tool driver interface to control I-beam firing, closure tube travel, shaft rotation, and articulation.

In one form, a strain gauge can be used to measure the force applied to the tissue by the end effector. A strain gauge can be coupled to the end effector to measure the force on the tissue being treated by the end effector. With reference now to FIG. **22**, a system **970** for measuring forces applied to the tissue grasped by the end effector comprises a strain gauge sensor **972**, such as, for example, a micro-strain gauge, is configured to measure one or more parameters of the end effector, for example. In one aspect, the strain gauge sensor **972** can measure the amplitude or magnitude of the strain exerted on a jaw member of an end effector during a clamping operation, which can be indicative of the tissue compression. The measured strain is converted to a digital signal and provided to a processor **962** of a microcontroller **961**. A load sensor **974** can measure the force to operate the knife element, for example, to cut the tissue captured between the anvil and the staple cartridge. A magnetic field sensor **976** can be employed to measure the thickness of the captured tissue. The measurement of the magnetic field sensor **976** also may be converted to a digital signal and provided to the processor **962**.

The measurements of the tissue compression, the tissue thickness, and/or the force required to close the end effector on the tissue, as respectively measured by the sensors **972**, **974**, **976**, can be used by the microcontroller **961** to characterize the selected position of the firing member and/or the corresponding value of the speed of the firing member. In one instance, a memory **968** may store a technique, an equation, and/or a look-up table which can be employed by the microcontroller **961** in the assessment.

In the aspect illustrated in FIG. **22**, a sensor **972**, such as, for example, a strain gauge or a micro-strain gauge, is configured to measure one or more parameters of the end effector **912**, such as, for example, the amplitude of the strain exerted on the anvil **914** during a clamping operation, which can be indicative of the closure forces applied to the anvil **914**. The measured strain is converted to a digital signal and provided to the processor **962**. Alternatively, or in addition to the sensor **972**, a sensor **974**, such as, for example, a load sensor, can measure the closure force applied by the closure drive system to the anvil **914**. The sensor **976**, such as, for example, a load sensor, can measure the firing force applied to an I-beam in a firing stroke of the robotic surgical system **10** (FIG. **1**). The I-beam is configured to engage a wedge sled, which is configured to upwardly cam staple drivers to force out staples into deforming contact with an anvil. The I-beam also includes a sharpened cutting edge that can be used to sever tissue as the I-beam is advanced distally by the firing bar. Alternatively, a current sensor **978** can be employed to measure the current drawn by the motor **982**. The force required to advance the firing member **220** can correspond to the current drawn by the motor **982**, for example. The measured force is converted to a digital signal and provided to the processor **962**.

FIG. **23** illustrates a control circuit configured to control aspects of the robotic surgical system **10** according to one aspect of this disclosure. FIG. **23** illustrates a control circuit **800** configured to control aspects of the robotic surgical system **10** according to one aspect of this disclosure. The control circuit **800** can be configured to implement various processes described herein. The control circuit **800** may comprise a controller comprising one or more processors **802** (e.g., microprocessor, microcontroller) coupled to at least one memory circuit **804**. The memory circuit **804** stores machine executable instructions that when executed by the processor **802**, cause the processor **802** to execute machine instructions to implement various processes described herein. The processor **802** may be any one of a number of single or multi-core processors known in the art. The memory circuit **804** may comprise volatile and non-volatile storage media. The processor **802** may include an instruction processing unit **806** and an arithmetic unit **808**. The instruction processing unit may be configured to receive instructions from the memory circuit **804** of this disclosure.

FIG. **24** illustrates a combinational logic circuit **810** configured to control aspects of the robotic surgical system **10** according to one aspect of this disclosure. The combinational logic circuit **810** can be configured to implement various processes described herein. The circuit **810** may comprise a finite state machine comprising a combinational logic circuit **812** configured to receive data associated with the robotic surgical system **10** at an input **814**, process the data by the combinational logic **812**, and provide an output **816**.

FIG. **25** illustrates a sequential logic circuit **820** configured to control aspects of the robotic surgical system **10** according to one aspect of this disclosure. The sequential logic circuit **820** or the combinational logic circuit **822** can be configured to implement various processes described herein. The circuit **820** may comprise a finite state machine. The sequential logic circuit **820** may comprise a combinational logic circuit **822**, at least one memory circuit **824**, and a clock **829**, for example. The at least one memory circuit **820** can store a current state of the finite state machine. In certain instances, the sequential logic circuit **820** may be synchronous or asynchronous. The combinational logic circuit **822** is configured to receive data associated with the robotic surgical system **10** an input **826**, process the data by the combinational logic circuit **822**, and provide an output **828**. In other aspects, the circuit may comprise a combination of the processor **802** and the finite state machine to implement various processes herein. In other aspects, the finite state machine may comprise a combination of the combinational logic circuit **810** and the sequential logic circuit **820**.

Aspects may be implemented as an article of manufacture. The article of manufacture may include a computer readable storage medium arranged to store logic, instructions, and/or data for performing various operations of one or more aspects. For example, the article of manufacture may comprise a magnetic disk, optical disk, flash memory, or firmware containing computer program instructions suitable for execution by a general purpose processor or application specific processor.

Referring primarily to FIG. **26** a robotic surgical system **10** may include a plurality of motors which can be activated to perform various functions. In certain instances, a first motor can be activated to perform a first function; a second motor can be activated to perform a second function; a third motor can be activated to perform a third function, a fourth motor can be activated to perform a fourth function, and so on. In certain instances, the plurality of motors of the robotic surgical instrument **4400** can be individually activated to cause firing, closure and/or articulation motions in the end effector **1012**. The firing, closure and/or articulation motions can be transmitted to the end effector **1012** through the shaft assembly **200**, for example.

In certain instances, the robotic surgical system **10** may include a firing motor **4402**. The firing motor **4402** may be operably coupled to a firing drive assembly **4404** which can be configured to transmit firing motions generated by the motor **4402** to the end effector **1012**, and in particular to displace the I-beam element. In certain instances, the firing motions generated by the motor **4402** may cause the staples to be deployed from the staple cartridge into tissue captured by the end effector and/or the cutting edge of the I-beam element to be advanced to cut the captured tissue, for example. The I-beam element may be retracted by reversing the direction of the motor **4402**.

In certain instances, the robotic surgical system **10** may include a closure motor **4403**. The closure motor **4403** may be operably coupled to a closure drive assembly **4405** which can be configured to transmit closure motions generated by the motor **4403** to the end effector **1012**, and in particular to displace the closure tube **1040**, **1042** to close the anvil **1024** and compress tissue between the anvil **1024** and the staple cartridge **1034**. The closure motions may cause the end effector **1012** to transition from an open configuration to an approximated configuration to capture tissue, for example. The end effector **102** may be transitioned to an open position by reversing the direction of the motor **4403**.

In certain instances, the robotic surgical instrument **10** may include one or more articulation motors **4406*a***, **4406*b***, for example. The motors **4406*a***, **4406*b*** may be operably coupled to respective articulation drive assemblies **4408*a***, **4408*b***, which can be configured to transmit articulation motions generated by the motors **4406*a***, **4406*b*** to the end effector **1012**. In certain instances, the articulation motions may cause the end effector to articulate relative to the shaft, for example.

As described above, the robotic surgical instrument **10** may include a plurality of motors which may be configured to perform various independent functions. In certain instances, the plurality of motors of the robotic surgical instrument **10** can be individually or separately activated to perform one or more functions while the other motors remain inactive. For example, the articulation motors **4406*a***, **4406*b*** can be activated to cause the end effector to be articulated while the firing motor **4402** remains inactive. Alternatively, the firing motor **4402** can be activated to fire the plurality of staples and/or advance the cutting edge while the articulation motor **4406** remains inactive. Furthermore the closure motor **4403** may be activated simultaneously with the firing motor **4402** to cause the closure tube **1040**, **1042** and the I-beam element to advance distally as described in more detail hereinbelow.

In certain instances, the robotic surgical system **10** may include a common control module **4410** which can be employed with a plurality of motors of the robotic surgical instrument **10**. In certain instances, the common control module **4410** may accommodate one of the plurality of motors at a time. For example, the common control module **4410** can be separably couplable to the plurality of motors of the robotic surgical instrument **10** individually. In certain instances, a plurality of the motors of the robotic surgical instrument **10** may share one or more common control modules such as the module **4410**. In certain instances, a plurality of motors of the robotic surgical instrument **10** can be individually and selectively engaged the common control module **4410**. In certain instances, the module **4410** can be selectively switched from interfacing with one of a plurality of motors of the robotic surgical instrument **10** to interfacing with another one of the plurality of motors of the robotic surgical instrument **10**.

In at least one example, the module **4410** can be selectively switched between operable engagement with the articulation motors **4406*a***, **4406*b*** and operable engagement with either the firing motor **4402** or the closure motor **4403**. In at least one example, as illustrated in FIG. **26**, a switch **4414** can be moved or transitioned between a plurality of positions and/or states. In a first position **4416** the switch **4414** may electrically couple the module **4410** to the firing motor **4402**; in a second position **4417**, the switch **4414** may electrically couple the module **4410** to the closure motor **4403**; in a third position **4418*a*** the switch **4414** may electrically couple the module **4410** to the first articulation motor **4406*a***; and in a fourth position **4418*b*** the switch **4414** may electrically couple the module **4410** to the second articulation motor **4406*b***, for example. In certain instances, separate modules **4410** can be electrically coupled to the firing motor **4402**, the closure motor **4403**, and the articulations motor **4406*a***, **4406*b*** at the same time, as shown, for example in FIG. **30**. In certain instances, the switch **4414** may be a mechanical switch, an electromechanical switch, a solid state switch, or any suitable switching mechanism.

Each of the motors **4402**, **4403**, **4406*a***, **4406*b*** may comprise a torque sensor to measure the output torque on the shaft of the motor. The force on an end effector may be sensed in any conventional manner such as by force sensors on the outer sides of the jaws or by a torque sensor for the motor actuating the jaws.

In various instances, as illustrated in FIG. **26**, the common control module **4410** may comprise a motor driver **4426** which may comprise one or more H-Bridge field-effect transistors (FETs). The motor driver **4426** may modulate the power transmitted from a power source **4428** to a motor coupled to the module **4410** based on input from a microcontroller **4420** ("controller"), for example. In certain instances, the controller **4420** can be employed to determine the current drawn by the motor, for example, while the motor is coupled to the module **4410**, as described above.

In certain instances, the controller **4420** may include a microprocessor **4422** ("processor") and one or more computer readable mediums or memory units **4424** ("memory"). In certain instances, the memory **4424** may store various program instructions, which when executed may cause the processor **4422** to perform a plurality of functions and/or calculations described herein. In certain instances, one or more of the memory units **4424** may be coupled to the processor **4422**, for example.

In certain instances, the power source **4428** can be employed to supply power to the controller **4420**, for example. In certain instances, the power source **4428** may comprise a battery (or "battery pack" or "power pack"), such as a Li ion battery, for example. In certain instances, the battery pack may be configured to be releasably mounted to the handle **14** for supplying power to the surgical instrument **4400**. A number of battery cells connected in series may be used as the power source **4428**. In certain instances, the power source **4428** may be replaceable and/or rechargeable, for example.

In various instances, the processor **4422** may control the motor driver **4426** to control the position, direction of rotation, and/or velocity of a motor that is coupled to the module **4410**. In certain instances, the processor **4422** can signal the motor driver **4426** to stop and/or disable a motor that is coupled to the module **4410**. It should be understood that the term processor as used herein includes any suitable microprocessor, microcontroller, or other basic computing device that incorporates the functions of a computer's central processing unit (CPU) on an integrated circuit or at most a few integrated circuits. The processor is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. Processors operate on numbers and symbols represented in the binary numeral system.

In one instance, the processor **4422** may be any single core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In certain instances, the microcontroller **4420** may be an LM 4F230H5QR, available from Texas Instruments, for example. In at least one example, the Texas Instruments LM4F230H5QR is an ARM Cortex-M4F Processor Core comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, internal ROM loaded with StellarisWare® software, 2 KB EEPROM, one or more PWM modules, one or more QEI analog, one or more 12-bit ADC with 12 analog input channels, among other features that are readily available for the product datasheet. Other microcontrollers may be readily substituted for use with the module **4410**. Accordingly, the present disclosure should not be limited in this context.

In certain instances, the memory **4424** may include program instructions for controlling each of the motors of the surgical instrument **4400** that are couplable to the module **4410**. For example, the memory **4424** may include program instructions for controlling the firing motor **4402**, the closure motor **4403**, and the articulation motors **4406***a*, **4406***b*. Such program instructions may cause the processor **4422** to control the firing, closure, and articulation functions in accordance with inputs from algorithms or control programs of the robotic surgical system **10**.

In certain instances, one or more mechanisms and/or sensors such as, for example, sensors **4430** can be employed to alert the processor **4422** to the program instructions that should be used in a particular setting. For example, the sensors **4430** may alert the processor **4422** to use the program instructions associated with firing, closing, and articulating the end effector **1012**. In certain instances, the sensors **4430** may comprise position sensors which can be employed to sense the position of the switch **4414**, for example. Accordingly, the processor **4422** may use the program instructions associated with firing the I-beam of the end effector **1012** upon detecting, through the sensors **4430** for example, that the switch **4414** is in the first position **4416**; the processor **4422** may use the program instructions associated with closing the anvil upon detecting, through the sensors **4430** for example, that the switch **4414** is in the second position **4417**; and the processor **4422** may use the program instructions associated with articulating the end effector **1012** upon detecting, through the sensors **4430** for example, that the switch **4418***a*, **4418***b* is in the third or fourth position **4418***a*, **4418***b*.

FIG. **27** is a diagram of an absolute positioning system **11100** of the robotic surgical instrument **10** where the absolute positioning system **11100** comprises a controlled motor drive circuit arrangement comprising a sensor arrangement **11102** according to one aspect of this disclosure. The sensor arrangement **11102** for an absolute positioning system **11100** provides a unique position signal corresponding to the location of a displacement member **11111**. In one aspect the displacement member **11111** represents the longitudinally movable drive member coupled to the cutting instrument or knife (e.g., cutting instrument **1032** in FIG. **11**A, I-beam **3005** in FIG. **12**, and/or I-beam **2514** in FIGS. **29-30**) comprising the first knife driven gear **1226** in meshing engagement with the knife spur gear **1222**, the second knife drive gear **1228** in meshing engagement with a third knife drive gear **1230** that is rotatably supported on the tool mounting plate **302** in meshing engagement with the knife rack gear **1206**. In other aspects, the displacement member **11111** represents a firing member coupled to the cutting instrument or knife, which could be adapted and configured to include a rack of drive teeth. In yet another aspect, the displacement member **11111** represents a firing bar or the I-beam **3005**, **2514** (FIGS. **12**, **30**), each of which can be adapted and configured to include a rack of drive teeth. Accordingly, as used herein, the term displacement member is used generically to refer to any movable member of the robotic surgical instrument **10** such as a drive member, firing member, firing bar, cutting instrument, knife, and/or I-beam, or any element that can be displaced.

Accordingly, the absolute positioning system **11100** can, in effect, track the displacement of the cutting instrument I-beam **3005**, **2514** (FIGS. **12**, **29-30**) by tracking the displacement of a longitudinally movable drive member. In various other aspects, the displacement member **11111** may be coupled to any sensor suitable for measuring displacement. Thus, a longitudinally movable drive member, firing member, the firing bar, or I-beam, or combinations thereof, may be coupled to any suitable displacement sensor. Displacement sensors may include contact or non-contact displacement sensors. Displacement sensors may comprise linear variable differential transformers (LVDT), differential variable reluctance transducers (DVRT), a slide potentiometer, a magnetic sensing system comprising a movable magnet and a series of linearly arranged Hall effect sensors, a magnetic sensing system comprising a fixed magnet and a series of movable linearly arranged Hall effect sensors, an optical sensing system comprising a movable light source and a series of linearly arranged photo diodes or photo detectors, or an optical sensing system comprising a fixed light source and a series of movable linearly arranged photo diodes or photo detectors, or any combination thereof.

An electric motor **11120** can include a rotatable shaft **11116** that operably interfaces with a gear assembly **11114** that is mounted in meshing engagement with a set, or rack, of drive teeth on the displacement member **11111**. A sensor element **11126** may be operably coupled to a gear assembly **11114** such that a single revolution of the sensor element **11126** corresponds to some linear longitudinal translation of the displacement member **11111**. An arrangement of gearing and sensors **11118** can be connected to the linear actuator via a rack and pinion arrangement or a rotary actuator via a spur gear or other connection. A power source **11129** supplies power to the absolute positioning system **11100** and an output indicator **11128** may display the output of the absolute positioning system **11100**. The interface for adapting to the motor **11120** is shown in FIGS. **4-6**, **8-10**, and **11**A, **11**B.

A single revolution of the sensor element **11126** associated with the position sensor **11112** is equivalent to a longitudinal displacement d**1** of the of the displacement member **11111**, where d**1** is the longitudinal distance that the displacement member **11111** moves from point "a" to point "b" after a single revolution of the sensor element **11126** coupled to the displacement member **11111**. The sensor arrangement **11102** may be connected via a gear reduction that results in the position sensor **11112** completing one or more revolutions for the full stroke of the displacement member **11111**. The position sensor **11112** may complete multiple revolutions for the full stroke of the displacement member **11111**.

A series of switches **11122***a*-**11122***n*, where n is an integer greater than one, may be employed alone or in combination with gear reduction to provide a unique position signal for more than one revolution of the position sensor **11112**. The state of the switches **11122***a*-**11122***n* are fed back to a controller **11104** that applies logic to determine a unique position signal corresponding to the longitudinal displacement d**1**+d**2**+ . . . dn of the displacement member **11111**. The output **11124** of the position sensor **11112** is provided to the controller **11104**. The position sensor **11112** of the sensor arrangement **11102** may comprise a magnetic sensor, an analog rotary sensor like a potentiometer, an array of analog Hall-effect elements, which output a unique combination of position signals or values. The controller **11104** may be contained within the master controller **11** or may be contained within the tool mounting portion housing **301**.

The absolute positioning system **11100** provides an absolute position of the displacement member **11111** upon power up of the robotic surgical instrument **10** without retracting or advancing the displacement member **11111** to a reset (zero or home) position as may be required with conventional rotary encoders that merely count the number of steps forwards or backwards that the motor **11120** has taken to infer the position of a device actuator, drive bar, knife, and the like.

The controller **11104** may be programmed to perform various functions such as precise control over the speed and position of the knife and articulation systems. In one aspect, the controller **11104** includes a processor **11108** and a memory **11106**. The electric motor **11120** may be a brushed DC motor with a gearbox and mechanical links to an articulation or knife system. In one aspect, a motor driver **11110** may be an A3941 available from Allegro Microsystems, Inc. Other motor drivers may be readily substituted for use in the absolute positioning system **11100**.

The controller **11104** may be programmed to provide precise control over the speed and position of the displacement member **11111** and articulation systems. The controller **11104** may be configured to compute a response in the software of the controller **11104**. The computed response is compared to a measured response of the actual system to obtain an "observed" response, which is used for actual feedback decisions. The observed response is a favorable, tuned, value that balances the smooth, continuous nature of the simulated response with the measured response, which can detect outside influences on the system.

The absolute positioning system **11100** may comprise and/or be programmed to implement a feedback controller, such as a PID, state feedback, and adaptive controller. A power source **11129** converts the signal from the feedback controller into a physical input to the system, in this case voltage. Other examples include pulse width modulation (PWM) of the voltage, current, and force. Other sensor(s) **11118** may be provided to measure physical parameters of the physical system in addition to position measured by the position sensor **11112**. In a digital signal processing system, absolute positioning system **1100** is coupled to a digital data acquisition system where the output of the absolute positioning system **11100** will have finite resolution and sampling frequency. The absolute positioning system **11100** may comprise a compare and combine circuit to combine a computed response with a measured response using algorithms such as weighted average and theoretical control loop that drives the computed response towards the measured response. The computed response of the physical system takes into account properties like mass, inertial, viscous friction, inductance resistance, etc., to predict what the states and outputs of the physical system will be by knowing the input.

The motor driver **11110** may be an A3941 available from Allegro Microsystems, Inc. The A3941 driver **11110** is a full-bridge controller for use with external N-channel power metal oxide semiconductor field effect transistors (MOSFETs) specifically designed for inductive loads, such as brush DC motors. The driver **11110** comprises a unique charge pump regulator provides full (>10 V) gate drive for battery voltages down to 7 V and allows the A3941 to operate with a reduced gate drive, down to 5.5 V. A bootstrap capacitor may be employed to provide the above-battery supply voltage required for N-channel MOSFETs. An internal charge pump for the high-side drive allows DC (100% duty cycle) operation. The full bridge can be driven in fast or slow decay modes using diode or synchronous rectification. In the slow decay mode, current recirculation can be through the high-side or the lowside FETs. The power FETs are protected from shoot-through by resistor adjustable dead time. Integrated diagnostics provide indication of undervoltage, overtemperature, and power bridge faults, and can be configured to protect the power MOSFETs under most short circuit conditions. Other motor drivers may be readily substituted for use in the absolute positioning system **11100**.

FIG. **28** is a diagram of a position sensor **11200** for an absolute positioning system **11100** comprising a magnetic rotary absolute positioning system according to one aspect of this disclosure. The position sensor **11200** may be implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **11200** is interfaced with the controller **11104** to provide an absolute positioning system **11100**. The position sensor **11200** is a low-voltage and low-power component and includes four Hall-effect elements **11228**A, **11228**B, **11228**C, **11228**D in an area **11230** of the position sensor **11200** that is located above a magnet **11202** positioned on a rotating element associated with a displacement member such as, for example, the knife drive gear **1228**, **1230** and/or the closure drive gear **1118**, **1120** such that the displacement of a firing member and/or a closure member can be precisely tracked. A high-resolution ADC **11232** and a smart power management controller **11238** are also provided on the chip. A CORDIC processor **11236** (for Coordinate Rotation Digital Computer), also known as the digit-by-digit method and Volder's algorithm, is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations. The angle position, alarm bits, and magnetic field information are transmitted over a standard serial communication interface such as an SPI interface **11234** to the controller **11104**. The position sensor **11200** provides 12 or 14 bits of resolution. The position sensor **11200** may be an AS5055 chip provided in a small QFN 16-pin 4×4×0.85 mm package.

The Hall-effect elements **11228**A, **11228**B, **11228**C, **11228**D are located directly above the rotating magnet **11202**. The Hall-effect is a well-known effect and for expediency will not be described in detail herein, however, generally, the Hall-effect produces a voltage difference (the Hall voltage) across an electrical conductor transverse to an electric current in the conductor and a magnetic field perpendicular to the current. A Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and properties of the charge carriers that constitute the current. In the AS5055 position sensor **11200**, the Hall-effect elements **11228**A, **11228**B, **11228**C, **11228**D are capable producing a voltage signal that is indicative of the absolute position of the magnet **11202** in terms of the angle over a single revolution of the magnet **11202**. This value of the angle, which is unique position signal, is calculated by the CORDIC processor **11236** is stored onboard the AS5055 position sensor **11200** in a register or memory. The value of the angle that is indicative of the position of the magnet **11202** over one revolution is provided to the controller **11104** in a variety of techniques, e.g., upon power up or upon request by the controller **11104**.

The AS5055 position sensor **11200** requires only a few external components to operate when connected to the controller **11104**. Six wires are needed for a simple application using a single power supply: two wires for power and four wires **11240** for the SPI interface **11234** with the controller **11104**. A seventh connection can be added in order to send an interrupt to the controller **11104** to inform that a new valid angle can be read. Upon power-up, the AS5055 position sensor **11200** performs a full power-up sequence including one angle measurement. The completion of this cycle is indicated as an INT output **11242**, and the angle value is stored in an internal register. Once this output is set, the AS5055 position sensor **11200** suspends to sleep mode. The controller **11104** can respond to the INT request at the INT output **11242** by reading the angle value from the AS5055 position sensor **11200** over the SPI interface **11234**. Once the angle value is read by the controller **11104**, the INT output **11242** is cleared again. Sending a "read angle" command by the SPI interface **11234** by the controller **11104** to the position sensor **11200** also automatically powers up the chip and starts another angle measurement. As soon as the controller **11104** has completed reading of the angle value, the INT output **11242** is cleared and a new result is stored in the angle register. The completion of the angle measurement is again indicated by setting the INT output **11242** and a corresponding flag in the status register.

Due to the measurement principle of the AS5055 position sensor **11200**, only a single angle measurement is performed in very short time (~600 μs) after each power-up sequence. As soon as the measurement of one angle is completed, the AS5055 position sensor **11200** suspends to power-down state. An on-chip filtering of the angle value by digital averaging is not implemented, as this would require more than one angle measurement and, consequently, a longer power-up time that is not desired in low-power applications. The angle jitter can be reduced by averaging of several angle samples in the controller **11104**. For example, an averaging of four samples reduces the jitter by 6 dB (50%).

FIG. **29** is a section view of an end effector **2502** of the robotic surgical instrument **10** showing an I-beam **2514** firing stroke relative to tissue **2526** grasped within the end effector **2502** according to one aspect of this disclosure. The end effector **2502** is configured to operate with the surgical instrument **10**. The end effector **2502** comprises an anvil **2516** and an elongated channel **2503** with a staple cartridge **2518** positioned in the elongated channel **2503**. A firing bar **2520** is translatable distally and proximally along a longitudinal axis **2515** of the end effector **2502**. When the end effector **2502** is not articulated, the end effector **2502** is in line with the shaft of the instrument. An I-beam **2514** comprising a cutting edge **2509** is illustrated at a distal portion of the firing bar **2520**. A wedge sled **2513** is positioned in the staple cartridge **2518**. As the I-beam **2514** translates distally, the cutting edge **2509** contacts and may cut tissue **2526** positioned between the anvil **2516** and the staple cartridge **2518**. Also, the I-beam **2514** contacts the wedge sled **2513** and pushes it distally, causing the wedge sled **2513** to contact staple drivers **2511**. The staple drivers **2511** may be driven up into staples **2505**, causing the staples **2505** to advance through tissue and into pockets **2507** defined in the anvil **2516**, which shape the staples **2505**.

An example I-beam **2514** firing stroke is illustrated by a chart **2529** aligned with the end effector **2502**. Example tissue **2526** is also shown aligned with the end effector **2502**. The firing member stroke may comprise a stroke begin position **2527** and a stroke end position **2528**. During an I-beam **2514** firing stroke, the I-beam **2514** may be advanced distally from the stroke begin position **2527** to the stroke end position **2528**. The I-beam **2514** is shown at one example location of a stroke begin position **2527**. The I-beam **2514** firing member stroke chart **2529** illustrates five firing member stroke regions **2517**, **2519**, **2521**, **2523**, **2525**. In a first firing stroke region **2517**, the I-beam **2514** may begin to advance distally. In the first firing stroke region **2517**, the I-beam **2514** may contact the wedge sled **2513** and begin to move it distally. While in the first region, however, the cutting edge **2509** may not contact tissue and the wedge sled **2513** may not contact a staple driver **2511**. After static friction is overcome, the force to drive the I-beam **2514** in the first region **2517** may be substantially constant.

In the second firing member stroke region **2519**, the cutting edge **2509** may begin to contact and cut tissue **2526**. Also, the wedge sled **2513** may begin to contact staple drivers **2511** to drive staples **2505**. Force to drive the I-beam **2514** may begin to ramp up. As shown, tissue encountered initially may be compressed and/or thinner because of the way that the anvil **2516** pivots relative to the staple cartridge **2518**. In the third firing member stroke region **2521**, the cutting edge **2509** may continuously contact and cut tissue **2526** and the wedge sled **2513** may repeatedly contact staple drivers **2511**. Force to drive the I-beam **2514** may plateau in the third region **2521**. By the fourth firing stroke region **2523**, force to drive the I-beam **2514** may begin to decline. For example, tissue in the portion of the end effector **2502** corresponding to the fourth firing region **2523** may be less compressed than tissue closer to the pivot point of the anvil **2516**, requiring less force to cut. Also, the cutting edge **2509** and wedge sled **2513** may reach the end of the tissue **2526** while in the fourth region **2523**. When the I-beam **2514** reaches the fifth region **2525**, the tissue **2526** may be completely severed. The wedge sled **2513** may contact one or more staple drivers **2511** at or near the end of the tissue. Force to advance the I-beam **2514** through the fifth region **2525** may be reduced and, in some examples, may be similar to the force to drive the I-beam **2514** in the first region **2517**. At the conclusion of the firing member stroke, the I-beam **2514** may reach the stroke end position **2528**. The positioning of firing member stroke regions **2517**, **2519**, **2521**, **2523**, **2525** in FIG. **29** is just one example. In some examples, different regions may begin at different positions along the end effector longitudinal axis **2515**, for example, based on the positioning of tissue between the anvil **2516** and the staple cartridge **2518**.

As discussed above and with reference now to FIGS. **27-29**, the electric motor **11122** positioned within the master controller **13** of the surgical instrument **10** can be utilized to advance and/or retract the firing system of the shaft assembly, including the I-beam **2514**, relative to the end effector **2502** of the shaft assembly in order to staple and/or incise tissue captured within the end effector **2502**. The I-beam **2514** may be advanced or retracted at a desired speed, or within a range of desired speeds. The controller **1104** may be configured to control the speed of the I-beam **2514**. The controller **11104** may be configured to predict the speed of the I-beam **2514** based on various parameters of the power supplied to the electric motor **11122**, such as voltage and/or current, for example, and/or other operating parameters of the electric motor **11122** or external influences. The controller **11104** may be configured to predict the current speed of the I-beam **2514** based on the previous values of the current and/or voltage supplied to the electric motor **11122**, and/or previous states of the system like velocity, acceleration, and/or position. The controller **11104** may be configured to sense the speed of the I-beam **2514** utilizing the absolute positioning sensor system described herein. The controller can be configured to compare the predicted speed of the I-beam **2514** and the sensed speed of the I-beam **2514** to determine whether the power to the electric motor **11122** should be increased in order to increase the speed of the I-beam **2514** and/or decreased in order to decrease the speed of the I-beam **2514**.

Force acting on the I-beam **2514** may be determined using various techniques. The I-beam **2514** force may be determined by measuring the motor **2504** current, where the motor **2504** current is based on the load experienced by the I-beam **2514** as it advances distally. The I-beam **2514** force may be determined by positioning a strain gauge on the drive member, the firing member, I-beam **2514**, the firing bar, and/or on a proximal end of the cutting edge **2509**. The I-beam **2514** force may be determined by monitoring the actual position of the I-beam **2514** moving at an expected velocity based on the current set velocity of the motor **11122** after a predetermined elapsed period T_1 and comparing the actual position of the I-beam **2514** relative to the expected position of the I-beam **2514** based on the current set velocity of the motor **11122** at the end of the period T_1. Thus, if the actual position of the I-beam **2514** is less than the expected position of the I-beam **2514**, the force on the I-beam **2514** is greater than a nominal force. Conversely, if the actual position of the I-beam **2514** is greater than the expected position of the I-beam **2514**, the force on the I-beam **2514** is less than the nominal force. The difference between the actual and expected positions of the I-beam **2514** is proportional to the deviation of the force on the I-beam **2514** from the nominal force.

FIG. **30** is a schematic diagram of a robotic surgical instrument **2500** configured to operate the surgical tool described herein according to one aspect of this disclosure. The robotic surgical instrument **2500** may be programmed or configured to control distal/proximal translation of a displacement member, closure tube distal/proximal displacement, shaft rotation, and articulation, either with single or multiple articulation drive links. In one aspect, the surgical instrument **2500** may be programmed or configured to individually control a firing member, a closure member, a shaft member, and/or one or more articulation members. The surgical instrument **2500** comprises a control circuit **2510** configured to control motor-driven firing members, closure members, shaft members, and/or one or more articulation members.

In one aspect, the robotic surgical instrument **2500** comprises a control circuit **2510** configured to control an anvil **2516** and an I-beam **2514** (including a sharp cutting edge) portion of an end effector **2502**, a removable staple cartridge **2518**, a shaft **2540**, and one or more articulation members **2542***a*, **2542***b* via a plurality of motors **2504***a*-**2504***e*. A position sensor **2534** may be configured to provide position feedback of the I-beam **2514** to the control circuit **2510**. Other sensors **2538** may be configured to provide feedback to the control circuit **2510**. A timer/counter **2531** provides timing and counting information to the control circuit **2510**. An energy source **2512** may be provided to operate the motors **2504***a*-**2504***e* and a current sensor **2536** provides motor current feedback to the control circuit **2510**. The motors **2504***a*-**2504***e* can be individually operated by the control circuit **2510** in open loop or closed loop feedback control.

In one aspect, the control circuit **2510**, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors. The control circuit **2510** may be implemented as control circuit **961** (FIG. **22**), **800** (FIG. **23**), **810** (FIG. **24**), **820** (FIG. **25**), **4420** (FIG. **26**). In one aspect, a timer/counter circuit **2531** provides an output signal, such as elapsed time or a digital count, to the control circuit **2510** to correlate the position of the I-beam **2514** as determined by the position sensor **2534** with the output of the timer/counter circuit **2531** such that the control circuit **2510** can determine the position of the I-beam **2514** at a specific time (t) relative to a starting position or the time (t) when the I-beam **2514** is at a specific position relative to a starting position. The timer/counter circuit **2531** may be configured to measure elapsed time, count external evens, or time external events.

In one aspect, the control circuit **2510** may be programmed to control functions of the end effector **2502** based on one or more tissue conditions. The control circuit **2510** may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit **2510** may be programmed to select a firing control program or closure control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit **2510** may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit **2510** may be programmed to translate the displacement member at a higher velocity and/or with higher power.

A closure control program may control the closure force applied to the tissue by the anvil **2516**. Other control programs control the rotation of the shaft **2540** and the articulation members **2542***a*, **2542***b*.

In one aspect, the control circuit **2510** may generate motor set point signals. The motor set point signals may be provided to various motor controllers **2508***a*-**2508***e*. The motor controllers **2508***a*-**2508***e* may comprise one or more circuits configured to provide motor drive signals to the motors **2504***a*-**2504***e* to drive the motors **2504***a*-**2504***e* as described herein. In some examples, the motors **2504***a*-**2504***e* may be brushed DC electric motors. For example, the velocity of the motors **2504***a*-**2504***e* may be proportional to the respective motor drive signals. In some examples, the motors **2504***a*-**2540***e* may be brushless direct current (DC) electric motors and the respective motor drive signals **2524***a*-**2524***e* may comprise a pulse-width-modulated (PWM) signal provided to one or more stator windings of the motors **2504***a*-**2504***e*. Also, in some examples, the motor controllers **2508***a*-**2508***e* may be omitted and the control circuit **2510** may generate the motor drive signals **2524***a*-**2524***e* directly.

In one aspect, the control circuit **2510** may initially operate each of the motors **2504***a*-**2504***e* in an open-loop configuration for a first open-loop portion of a stroke of the displacement member. Based on a response of the instrument **2500** during the open-loop portion of the stroke, the control circuit **2510** may select a firing control program in a closed-loop configuration. The response of the instrument may include, a translation distance of the displacement member during the open-loop portion, a time elapsed during the open-loop portion, energy provided to the motor **2504** during the open-loop portion, a sum of pulse widths of a motor drive signal, etc. After the open-loop portion, the control circuit **2510** may implement the selected firing control program for a second portion of the displacement member stroke. For example, during a closed loop portion of the stroke, the control circuit **2510** may modulate the motor **2504** based on translation data describing a position of the displacement member in a closed-loop manner to translate the displacement member at a constant velocity.

In one aspect, the motors **2504***a*-**2504***e* may receive power from an energy source **2512**. The energy source **2512** may be a DC power supply driven by a main AC power source, a battery, a super capacitor, or any other suitable energy source **2512**. The motors **2504***a*-**2504***e* may be mechanically coupled to individual movable mechanical elements such as the I-beam **2514**, anvil **2516**, shaft **2540**, articulation **2542***a*, articulation **2542***b* via respective transmissions **2506***a*-**2506***e*. The transmissions **2506***a*-**2506***e* may include one or more gears or other linkage components to couple the motors **2504***a*-**2504***e* to movable mechanical elements. A position sensor **2534** may sense a position of the I-beam **2514**. The position sensor **2534** may be or include any type of sensor that is capable of generating position data that indicates a position of the I-beam **2514**. In some examples, the position sensor **2534** may include an encoder configured to provide a series of pulses to the control circuit **2510** as the I-beam **2514** translates distally and proximally. The control circuit **2510** may track the pulses to determine the position of the I-beam **2514**. Other suitable position sensor may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **2514**. Also, in some examples, the position sensor **2534** may be omitted. Where any of the motors **2504***a*-**2504***e* is a stepper motor, the control circuit **2510** may track the position of the I-beam **2514** by aggregating the number and direction of steps that the motor **2504** has been instructed to execute. The position sensor **2534** may be located in the end effector **2502** or at any other portion of the instrument. The outputs of each of the motors **2504***a*-**2504***e* includes a torque sensor **2544***a*-**2544***e* to sense force and has an encoder to sense rotation of the drive shaft.

In one aspect, the control circuit **2510** is configured to drive a firing member such as the I-beam **2514** portion of the end effector **2502**. The control circuit **2510** provides a motor set point to a motor control **2508***a*, which provides a drive signal to the motor **2504***a*. The output shaft of the motor **2504***a* is coupled to a torque sensor **2544***a* and a transmission **2506***a* which is coupled to the I-beam **2514**. The transmission **2506***a* comprises movable mechanical elements such as rotating elements and a firing member to control the movement of the I-beam **2514** distally and proximally along a longitudinal axis of the end effector **2502**. In one aspect, the motor **2504***a* may be coupled to the knife gear assembly **1220**, which includes a knife gear reduction set **1224** that includes a first knife drive gear **1226** and a second knife drive gear **1228**. As can be seen in FIGS. **9** and **10**, the knife gear reduction set **1224** is rotatably mounted to the tool mounting plate **302** such that the first knife drive gear **1226** is in meshing engagement with the knife spur gear **1222**. Likewise, the second knife drive gear **1228** is in meshing engagement with a third knife drive gear **1230** that is rotatably supported on the tool mounting plate **302** in meshing engagement with the knife rack gear **1206**. A torque sensor **2544***a* provides a firing force feedback signal to the control circuit **2510**. The firing force signal represents the force required to fire or displace the I-beam **2514**. A position sensor **2534** may be configured to provide the position of the I-beam **2514** along the firing stroke or the position of the firing member as a feedback signal to the control circuit **2510**. The end effector **2502** may include additional sensors **2538** configured to provide feedback signals to the control circuit **2510**. When ready to use, the control circuit **2510** may provide a firing signal to the motor control **2508***a*. In response to the firing signal, the motor **2504***a* may drive the firing member distally along the longitudinal axis of the end effector **2502** from a proximal stroke begin position to a stroke end position distal of the stroke begin position. As the firing member translates distally, an I-beam **2514** with a cutting element positioned at a distal end, advances distally to cut tissue located between the staple cartridge **2518** and the anvil **2516**.

In one aspect, the control circuit **2510** is configured to drive a closure member such as the anvil **2516** portion of the end effector **2502**. The control circuit **2510** provides a motor set point to a motor control **2508***b*, which provides a drive signal to the motor **2504***b*. The output shaft of the motor **2504***b* is coupled to a torque sensor **2544***b* and a transmission **2506***b* which is coupled to the anvil **2516**. The transmission **2506***b* comprises movable mechanical elements such as rotating elements and a closure member to control the movement of the anvil **2516** from open and closed positions. In one aspect, the motor **2504***b* is coupled to the closure gear assembly **1110**, which includes a closure reduction gear set **1114** that is supported in meshing engagement with the closure spur gear **1112**. As can be seen in FIGS. **9** and **10**, the closure reduction gear set **1114** includes a driven gear **1116** that is rotatably supported in meshing engagement with the closure spur gear **1112**. The closure reduction gear set **1114** further includes a first closure drive gear **1118** that is in meshing engagement with a second closure drive gear **1120** that is rotatably supported on the tool mounting plate

302 in meshing engagement with the closure rack gear **1106**. The torque sensor **2544***b* provides a closure force feedback signal to the control circuit **2510**. The closure force feedback signal represents the closure force applied to the anvil **2516**. The position sensor **2534** may be configured to provide the position of the closure member as a feedback signal to the control circuit **2510**. Additional sensors **2538** in the end effector **2502** may provide the closure force feedback signal to the control circuit **2510**. The pivotable anvil **2516** is positioned opposite the staple cartridge **2518**. When ready to use, the control circuit **2510** may provide a closure signal to the motor control **2508***b*. In response to the closure signal, the motor **2504***b* advances a closure member to grasp tissue between the anvil **2516** and the staple cartridge **2518**.

In one aspect, the control circuit **2510** is configured to rotate a shaft member such as the shaft **2540** to rotate the end effector **2502**. The control circuit **2510** provides a motor set point to a motor control **2508***c*, which provides a drive signal to the motor **2504***c*. The output shaft of the motor **2504***c* is coupled to a torque sensor **2544***c* and a transmission **2506***c* which is coupled to the shaft **2540**. The transmission **2506***c* comprises movable mechanical elements such as rotating elements to control the rotation of the shaft **2540** clockwise or counterclockwise up to and over 360°. In one aspect, the motor **2504***c* is coupled to the rotational transmission assembly **1069**, which includes a tube gear segment **1062** that is formed on (or attached to) the proximal end **1060** of the proximal closure tube **1040** for operable engagement by a rotational gear assembly **1070** that is operably supported on the tool mounting plate **302**. As shown in FIG. **8**, the rotational gear assembly **1070**, in at least one aspect, comprises a rotation drive gear **1072** that is coupled to a corresponding first one of the driven discs or elements **304** on the adapter side **307** of the tool mounting plate **302** when the tool mounting portion **300** is coupled to the tool drive assembly **101**. See FIG. **6**. The rotational gear assembly **1070** further comprises a rotary driven gear **1074** that is rotatably supported on the tool mounting plate **302** in meshing engagement with the tube gear segment **1062** and the rotation drive gear **1072**. The torque sensor **2544***c* provides a rotation force feedback signal to the control circuit **2510**. The rotation force feedback signal represents the rotation force applied to the shaft **2540**. The position sensor **2534** may be configured to provide the position of the closure member as a feedback signal to the control circuit **2510**. Additional sensors **2538** such as a shaft encoder may provide the rotational position of the shaft **2540** to the control circuit **2510**.

In one aspect, the control circuit **2510** is configured to articulate the end effector **2502**. The control circuit **2510** provides a motor set point to a motor control **2508***d*, which provides a drive signal to the motor **2504***d*. The output shaft of the motor **2504***d* is coupled to a torque sensor **2544***d* and a transmission **2506***d* which is coupled to an articulation member **2542***a*. The transmission **2506***d* comprises movable mechanical elements such as articulation elements to control the articulation of the end effector **2502** ±65°. In one aspect, the motor **2504***d* is coupled to the articulation nut **1260**, which is rotatably journaled on the proximal end portion of the distal spine portion **1050** and is rotatably driven thereon by an articulation gear assembly **1270**. More specifically and with reference to FIG. **8**, in at least one aspect, the articulation gear assembly **1270** includes an articulation spur gear **1272** that is coupled to a corresponding fourth one of the driven discs or elements **304** on the adapter side **307** of the tool mounting plate **302**. The torque sensor **2544***d* provides an articulation force feedback signal to the control circuit **2510**. The articulation force feedback signal represents the articulation force applied to the end effector **2502**. Sensors **2538** such as an articulation encoder may provide the articulation position of the end effector **2502** to the control circuit **2510**.

In another aspect, the articulation function of the robotic surgical system **10** may comprise two drive members **2542***a*, **2542***b* or links. These drive members **2542***a*, **2542***b* are driven by separate disks on the robot interface (the rack) which are driven by the two motors **2508***d*, **2508***e*. When the separate firing motor **2504***a* is provided, each articulation link **2542***a*, **2542***b* can be antagonistically driven with respect to the other link in order to provide resistive holding motion and load to the head when it is not moving and to provide articulation motion as the head is articulated. The drive members **2542***a*, **2542***b* or links attach to the head at a fixed radius as the head is rotated. Accordingly, the mechanical advantage of the push and pull link changes as the head is rotated. This change in the mechanical advantage may be more pronounced with other articulation link drive systems.

In one aspect, the end effector **2502** may be implemented as the surgical end effector **1012**, **3000**, **5650**, **6460**, **6470** shown and described in connection with FIGS. **4**, **6**, **8-12**, **15**A, **15**B, **19**, **20**, and **21**. In one aspect, the I-beam **2514** portion of the end effector **2502** may be implemented as the knife member **1032**, **3005**, **2514** shown and described in connection with FIGS. **11**A, **12**, **29**. The I-beam **2514** comprises a knife body that operably supports a tissue cutting blade **2509** (FIG. **29**) thereon. In one aspect, the anvil **2516** portion of the end effector **2502** may be implemented as the anvil **1024**, **3002**, **5502**, **5602**, **6472** shown and described in connection with FIGS. **4**, **6-14**, **20**, and **21**.

In one aspect, the one or more motors **2504***a*-**2504***e* may comprise a brushed DC motor with gearbox and mechanical links to a firing member, closure member, or articulation member. Another example are electric motors **2504***a*-**2504***e* that operate the movable mechanical elements such as the displacement member, articulation links, closure tube, and shaft. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies and friction on the physical system. Such outside influence can be referred to as drag which acts in opposition to an electric motor **2504***a*-**2504***e*. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

In one aspect, the position sensor **2534** may be implemented as an absolute positioning system as shown and described in connection with FIGS. **27** and **28**. In one aspect, the position sensor **2534** may comprise a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **2534** may interface with the control circuit **2510** to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor (for Coordinate Rotation Digital Computer), also known as the digit-by-digit method and Volder's algorithm, is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

In one aspect, the control circuit **2510** may be in communication with one or more sensors **2538**. The sensors **2538** may be positioned on the end effector **2502** and adapted to operate with the surgical instrument **2500** to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **2538** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a load cell, a pressure sensor, a force sensor, a torque sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **2502**. The sensors **2538** may include one or more sensors. The sensors **2538** may be located on the staple cartridge **2518** deck to determine tissue location using segmented electrodes. The torque sensors **2544***a*-**2544***e* may be configured to sense force such as firing force, closure force, articulation force, among others. Accordingly, the control circuit **26510** can sense: (1) the closure load experienced by the distal closure tube and its position; (2) the firing member at the rack and its position; (3) what portion of the staple cartridge **2518** has tissue on it; and (4) sense the load and position on both articulation rods.

In one aspect, the one or more sensors **2538** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **2516** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **2538** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **2516** and the staple cartridge **2518**. The sensors **2538** may be configured to detect impedance of a tissue section located between the anvil **2516** and the staple cartridge **2518** that is indicative of the thickness and/or fullness of tissue located therebetween.

In one aspect, the sensors **2538** may be implemented as one or more limit switches, electromechanical devices, solid state switches, Hall-effect devices, magneto-resistive (MR) devices, giant magneto-resistive (GMR) devices, magnetometers, among others. In other implementations, the sensors **2538** may be implemented as solid state switches that operate under the influence of light, such as optical sensors, infrared sensors, ultraviolet sensors, among others. Still, the switches may be solid state devices such as transistors (e.g., FET, Junction-FET, metal-oxide semiconductor-FET (MOSFET), bipolar, and the like). In other implementations, the sensors **2538** may include electrical conductorless switches, ultrasonic switches, accelerometers, inertial sensors, among others.

In one aspect, the sensors **2538** may be configured to measure forces exerted on the anvil **2516** by the closure drive system. For example, one or more sensors **2538** can be at an interaction point between the closure tube and the anvil **2516** to detect the closure forces applied by the closure tube to the anvil **2516**. The forces exerted on the anvil **2516** can be representative of the tissue compression experienced by the tissue section captured between the anvil **2516** and the staple cartridge **2518**. The one or more sensors **2538** can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil **2516** by the closure drive system. The one or more sensors **2538** may be sampled in real time during a clamping operation by the processor of the control circuit **2510**. The control circuit **2510** receives real-time sample measurements to provide analyze time based information and assess, in real time, closure forces applied to the anvil **2516**.

In one aspect, a current sensor **2536** can be employed to measure the current drawn by each of the motors **2504***a*-**2504***e*. The force required to advance any of the movable mechanical elements such as the I-beam **2514** corresponds to the current drawn by a motor **2504***a*-**2504***e*. The force is converted to a digital signal and provided to the control circuit **2510**. The control circuit **2510** can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam **2514** in the end effector **2502** at or near a target velocity. The robotic surgical instrument **2500** can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a State Feedback, LQR, and/or an Adaptive controller, for example. The robotic surgical instrument **2500** can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, pulse width modulated (PWM) voltage, frequency modulated voltage, current, torque, and/or force, for example.

In use, a robotic surgical instrument may sense and identify certain tissue conditions in the end effector that may affect performance of the staple formation and tissue cutting process. Accordingly, in such situations, the displacement, e.g., advancement or retraction, process for controlling the velocity of the firing member may be based on the sensed and identified parameters of tissue gap, coupling member load, knife advancement rate, and tissue compression In one aspect, the present disclosure provides various techniques for controlling the advancement or retraction velocity of a displacement member of a robotic surgical instrument based on the sensed and identified parameters of end effector gap (e.g., indicative of tissue thickness), coupling member load such as closure force (FTC) or firing force (FTF), knife advancement rate, tissue impedance, tissue compression, tissue coverage on cartridge, among other parameters.

FIG. **31** is a chart **12000** illustrating techniques for controlling the advancement or retraction velocity of a displacement member of a robotic surgical instrument according to one aspect of this disclosure. The chart **12000** depicts firing the displacement member from an anvil closure condition or from a firing condition for tissue that is thinner than anticipated or thicker than anticipated. The first column **12002** tabulates variables or parameters that the velocity control is based on such as end effector gap between the anvil and the staple cartridge, closure force or firing force, velocity of the knife, tissue impedance, and tissue coverage on the cartridge. The second column **12004** tabulates the initial velocity selection from closure of the anvil of either slow or fast, otherwise known as the set velocity or command velocity based on the sensed and identified parameters tabulated in the first column **12002**. The third column **12006** tabulates decreasing or increasing firing velocity updates over the length of the cartridge (e.g., the main Xmm in different sections, where X is the length of the cartridge such as 10 mm-60 mm, or greater) based on the sensed and identified parameters tabulated in the first column **12002**.

Accordingly, with reference now to the firing process from closure during the anvil closure phase tabulated in the second column **12004** based on the tissue gap parameter, if the measured tissue gap in the end effector is less than a nominal tissue gap and the initial set velocity of the displacement member is slow, the velocity of the displacement member is increased as indicated by the ++ symbol, where the number of the "+" or "−" symbols refers to proportionally increase or decrease the set velocity, respectively. In contrast, if the measured tissue gap is greater than the nominal tissue gap and the initial set velocity of the displacement member is fast, the velocity of the displacement member is decreased as indicated by the −− symbol.

With reference now to the firing process from closure during the anvil closure phase tabulated in the second column **12004** based on the closure force (FTC) parameter, if the measured FTC is less than a threshold force and the initial set velocity of the displacement member is slow, the velocity of the displacement member may be increased as indicated by the ++ symbol. In contrast, if the measured FTC is greater than the threshold force and the initial set velocity of the displacement member is fast, the velocity of the displacement member is decreased as indicated by the −− symbol.

The next variable, the knife velocity parameter (e.g., velocity of the displacement member), is skipped because the initial velocity of the knife from closure is always zero. Accordingly, turning now to the firing process from closure during the anvil closure phase tabulated in the second column **12004** based on the tissue impedance parameter, if the measured tissue impedance is lower than expected, indicating that the tissue is thinner than expected, and the initial set velocity of the displacement member is slow, the velocity of the displacement member may be increased as indicated by the ++ symbol. In contrast, if the measured tissue impedance is greater than the threshold tissue impedance, indicating that the tissue is thicker than expected, and the initial set velocity of the displacement member is fast, the velocity of the displacement member is decreased as indicated by the −− symbol.

With reference now to the firing process from closure during the anvil closure phase tabulated in the second column **12004** based on cartridge coverage parameter, for example, based on tissue partially or entirely covering the space between the anvil and staple cartridge, if the measured tissue does not cover the entire cartridge and the initial set velocity of the displacement member is slow, the velocity of the displacement member may be increased as indicated by the + symbol. In contrast, if the measured tissue covers the entire cartridge and the initial set velocity of the displacement member is fast, the velocity of the displacement member is decreased as indicated by the − symbol.

The description now turns to the firing phase tabulated in the third column **12006**. Accordingly, with reference to the tissue gap parameter, if during the firing phase at the current set firing velocity, the measured tissue gap in the end effector decreases, the velocity of the displacement member is increased as indicated by the + symbol. In contrast, if during the firing phase at the current set firing velocity, the measured tissue gap in the end effector increases, the velocity of the displacement member is decreased as indicated by the − symbol.

With reference to the FTF parameter, if during the firing phase at the current set firing velocity, the measured FTF decreases, the set velocity of the displacement member is increased as indicated by the ++ symbol. In contrast, if during the firing phase at the current set firing velocity, the measured FTF increases, the set velocity of the displacement member is decreased as indicated by the −− symbol.

With reference to the knife velocity parameter (e.g., velocity of the displacement) as indicated in the third column **12006** the − symbol indicates a decrease in set velocity and the + symbol indicates an increase in set velocity. Accordingly, turning now to the tissue impedance parameter, if during the firing phase at the current set firing velocity, the measured tissue impedance decreases (indicating a decrease in tissue thickness), the set velocity of the displacement member is increased as indicated by the + symbol. In contrast, if during the firing phase at the current set firing velocity, the measured tissue impedance increases (indicating an increase in tissue thickness), the set velocity of the displacement member is decreased as indicated by the − symbol.

Finally, with reference now to the cartridge coverage parameter, if during the firing phase at the current set firing velocity, the measured cartridge coverage decreases, the set velocity of the displacement member is increased as indicated by the + symbol. In contrast, if during the firing phase at the current set firing velocity, the measured cartridge coverage increases, the set velocity of the displacement member is decreased as indicated by the − symbol.

With the above background, the description now turns to FIG. **32**, which is a graphical depiction of a closed loop velocity control process **12100** according to one aspect of this disclosure. The top graph **12102** depicts variation in tissue thickness as a function of position along the staple cartridge. The horizontal axis **12142** is scaled to represent the length of the staple cartridge Xmm, where X is 10-60 mm, for example. Accordingly, for a 60 mm staple cartridge, X=60 mm. The vertical axis **12144** represents tissue thickness T (mm). The horizontal axis **242** also is divided into four zones (Zone 1-Zone 4) of equal length. As shown, the thickness of the tissue **12110** varies 0.25X to 0.74X (15-45 mm for a 60 mm cartridge). The control circuit monitors the tissue thickness along the length of the cartridge and compares the thickness of the tissue **12110** to a threshold thickness **12115**. The tissue **12110** thickness plot indicates that tissue is located only in Zone 2 and Zone 3 of the cartridge and not in Zone 1 and Zone 4. Also, the thickness of tissue **12110** is above the threshold thickness **12115** between δ_1 and δ_2 such that tissue segments **12112**, **12116** are below the threshold thickness **12115** and the thickness of a portion of tissue **12114** is located above the threshold thickness **12115**. Accordingly, as discussed in the chart **12000** in FIG. **31**, the closed loop velocity control process will be adjusted based on the tissue condition parameters encountered in the closure phase and the firing phase.

The second graph **12104** from the top depicts tissue **12110** coverage as a function of position along staple cartridge, where the horizontal axis **12142** represents the length of the staple cartridge Xmm, and the vertical axis **12148** represents the presence of tissue **12110** in a particular zone (Zone 1-Zone 4). The cartridge coverage is represented as a binary variable such that if tissue **12110** is present, the cartridge coverage is 1 and if tissue **12110** is not present the cartridge coverage is 0. As shown, the cartridge coverage is 0 in Zone 1 and Zone 4 and is 1 in Zone 2 and Zone 3.

The third graph **12106** from the top, depicts firing force (N) as a function of position along the staple cartridge for slow and fast traversal rates and for a controlled velocity. The horizontal axis **12150** represents the length of the staple cartridge Xmm, and the vertical axis **12148** represents firing force (N). As shown, the slow rate FTF curve **12126** has a lower force profile that the fast rate curve **12130**. The controlled curve **12128** represents the force profile when the process **12200** discussed in reference to FIG. **33** is executed by the control circuit **2510** (FIG. **30**). Generally, when the knife or the displacement member encounters tissue **12110** that is thicker that the threshold thickness **12115** the control circuit decreases the set velocity of the displacement member as discussed in more detail in reference to the bottom graph **12108**.

The bottom graph **12108** represents command velocity **12118** (dashed line) and actual velocity **12120** (solid line) as a function of position along the staple cartridge where the horizontal axis **12154** represents the length of the staple cartridge Xmm and the vertical axis **12156** represents command velocity (mm/sec). The command velocity **12118** is the motor velocity set by the control circuit and the actual velocity **12120** is the actual velocity as measured by the control circuit via feedback from the position sensor and timer/counter circuit. The command velocity **12118** is determined based on the tissue conditions experienced during the initial closure phase and the firing phase. The control circuit adjusts the command velocity **12118** based on the closed loop control process **12200** described in reference to FIG. **33** to compensate, for example, for tissue thickness and cartridge coverage. Nevertheless, the command velocity **12118** may be adjusted by the closed loop control process **12200** based on any of the parameters or variables described in the first column **12002** of the chart **12000** shown in FIG. **31**.

In the example of FIG. **32**, upon detecting that there is no tissue in Zone 1, the control circuit increases the command velocity from 0 mm/sec to V_{HIGH} **12122** during the Zone 1 period until tissue **12110** is encountered by the I-beam knife at the beginning of Zone 2 (0.25 Xmm) at which point the command velocity **12118** is decreased to the velocity V_{LOW} **12124**. The velocity V_{LOW} **12124** is maintained until the I-beam knife exits Zone 3 (0.75X) at which point the control circuit adjusts the command velocity **12118** back to V_{HIGH} **12125** in Zone 4. The actual velocity **12120** profile substantially tracks the command velocity **12118**, but includes a response time delay between the time that the command velocity **12118** is set by the control circuit until the displacement member reaches the command velocity **12118**. For example, the actual velocity segment **12132** reaches V_{HIGH} **12122** and droops slightly in Zone 1 due to the compression force applied to the tissue **12110**. In Zone 2, the actual velocity **12120** drops as shown by segment **12134** as the displacement member tracks the command velocity **12118**. In Zone 2, between δ_1 and δ_2 where the tissue thickness of tissue segment **12114** is above the tissue thickness threshold **12115**. Accordingly, in Zone 2, the actual velocity **12120** segment **12136** is slightly lower than the command velocity **12118** due to the thicker tissue segment **12114** encountered by the I-beam knife. In Zone 3, as the tissue segment **12116** drops below the tissue thickness threshold **12115** but remains above zero, the actual velocity **12120** segment **12138** tracks the command velocity **12118** V_{LOW} **12124** more closely. Finally, in Zone 4, a tissue free zone, the actual velocity **12120** ramps up to the command velocity **12125**. The actual velocity segment **12140** rises slightly above V_{HIGH} and then drops to zero at the end of stroke. Referring to the controlled curve **12128**, the firing force profile drops significantly by reducing the command velocity **12118** and accordingly, the actual velocity **12120** or advancement velocity of the I-beam knife.

FIG. **33** is a logic flow diagram depicting a process **12200** of a control program or a logic configuration for determining tissue conditions in an end effector and adjusting command velocity accordingly according to one aspect of this disclosure. The process **12200** will be described in reference to the robotic surgical instrument **2500** shown in FIG. **30** programmed to control distal translation of a displacement member, closure tube travel, shaft rotation, and articulation, either with single or dual articulation drive links, according to one aspect of this disclosure. One or more sensors **2538** of the robotic surgical instrument **2500** detect **12202** tissue conditions in the end effector **2502** during an anvil **2516** closure phase, e.g., while the anvil **2516** closes on the staple cartridge **2518**. The outputs of thee one or more sensors **2538** are provided to the control circuit **2510**. The control circuit **2510** sets **12204** the command velocity of the motor **2504***a* by applying a motor set point to the motor control **2508***a* which in turn applies a motor drive signal to the motor **2504***a* to set the command velocity of the motor **2504***a* to drive or fire **12206** the displacement member coupled to the I-beam **2514** at the command velocity during the closure phase. The torque sensor **2544***a* at the output shaft of the motor **2504***a* may provide a torque signal to the additional control circuit **2510** to detect force encountered by the I-beam **2514** during travel within the end effector **2502**. A position sensor **2534** is configured to detect the position of the I-beam **2514** or other displacement member of the robotic surgical system **2500**.

The process **12200** continues during the firing phase. Accordingly, the one or more sensors **2538** detect **12208** tissue conditions in the end effector **2502** during the firing phase of the I-beam **2514**. The control circuit **2510** receives inputs from the one or more sensor **2538** and additionally from the torques sensor **2544***a*, the position sensor **2534**, and optionally the current sensor **2536** to set **12210** the command velocity of the displacement member coupled to the I-beam **2514** based on the detected **12208** tissue conditions. The displacement member advances at the set velocity until changes in the tissue conditions are detected **12212**. The command velocity is then adjusted **12210** to a new command velocity based on the detected **12212** tissue conditions. Reference is made to the chart **12000** in FIG. **31** and accompanying description for firing the displacement member from an anvil **2516** closure condition or from a firing condition for tissue based on tissue conditions encountered in the end effector **2502**. The process **12200** continues **12214** until the displacement member, e.g., the I-beam **2514**, reaches the end of stroke **12216**.

According to the process **12200** the control circuit **2510** of the robotic surgical system **2500** is configured to detect **12202** a condition at an end effector **2502** during a closure phase. The control circuit **2510** sets **12204** the command velocity of the motor **2504***a* coupled to a displacement member, e.g., the I-beam **2514**, coupled to the end effector **2502** based on the detected **12202** condition at the end effector **2502** during the closure phase. The control circuit **2510** fires **12206** the displacement member at the set command velocity. The control circuit **2510** detects **12208** a condition at the end effector **2502** during a firing phase. The control circuit sets **1210** the command velocity of the motor **2504***a* based on the condition detected **12208** at the end effector **2502** during the firing phase.

During the closure phase or the firing phase, the control circuit **2510** of the robotic surgical system **2500** is configured to detect tissue thickness based on sensors **2538** and is configured to detect a gap defined between the anvil **2516** and the staple cartridge **2518** portion of the end effector **2502** based on the sensors **2538** and adjust the command velocity based on the gap and the command velocity at the time the gap is detected. Tissue thickness may be detected by various sensors **2538** such as those shown in FIGS. **13-21** and accompanying description.

The control circuit **2510** may be configured to detect a closure force defined as the force experienced by the anvil **2516** and the staple cartridge **2518** portion of the end effector **2502** closed on tissue located therebetween and adjusts the command velocity based on the closure force and the command velocity at the time the force is detected. The force may be detected by force sensors, such as strain gauges, located in the anvil **2516** or the staple cartridge **2518** or other location in the end effector **2502** such as those shown in FIGS. **13-21** and accompanying description. In addition the closure force may be provided by the torque sensor **2544***b* coupled to a second motor **2508***b*.

The control circuit **2510** may be configured to detect a firing force to displace the displacement member and adjust the command velocity based on the firing force and the command velocity at the time the force is detected. The firing force may be provided to the control circuit **2510** by sensors **2538** or the torque sensor **2544***a* coupled to the output shaft of the motor **2508***a*.

The control circuit **2510** may be configured to detect the electrical impedance of the tissue located between the anvil **2516** and the staple cartridge **2518** of the end effector **2502** and adjust the command velocity based on the electrical impedance and the command velocity at the time the impedance is detected. The electrical impedance may be sensed using a variety of sensors **2538** such as those shown in FIGS. **13**-**21** and accompanying description. Electrical current driven through the tissue located between the electrode segments can be used by the control circuit **2510** to measure the tissue impedance.

The control circuit **2510** may be configured to detect the coverage of tissue located between an anvil and a staple cartridge portion of the end effector and adjust the command velocity based on the coverage and the command velocity at the time the coverage is detected. Tissue coverage may be detected using various sensors such as those shown in FIGS. **13**-**21** and accompanying description.

The functions or processes **12000** described herein may be executed by any of the processing circuits described herein, such as the control circuit **961** (FIG. **22**), **800** (FIG. **23**), **810** (FIG. **24**), **820** (FIG. **25**), **4420** (FIG. **26**), and/or control circuit **2510** (FIG. **30**). Aspects of the motorized surgical instrument may be practiced without the specific details disclosed herein. Some aspects have been shown as block diagrams rather than detail.

Parts of this disclosure may be presented in terms of instructions that operate on data stored in a computer memory. An algorithm refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities which may take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. These signals may be referred to as bits, values, elements, symbols, characters, terms, numbers. These and similar terms may be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities.

Generally, aspects described herein which can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or any combination thereof can be viewed as being composed of various types of "electrical circuitry." Consequently, "electrical circuitry" includes electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit, electrical circuitry forming a general purpose computing device configured by a computer program (e.g., a general purpose computer or processor configured by a computer program which at least partially carries out processes and/or devices described herein, electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). These aspects may be implemented in analog or digital form, or combinations thereof.

The foregoing description has set forth aspects of devices and/or processes via the use of block diagrams, flowcharts, and/or examples, which may contain one or more functions and/or operation. Each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In one aspect, several portions of the subject matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), Programmable Logic Devices (PLDs), circuits, registers and/or software components, e.g., programs, subroutines, logic and/or combinations of hardware and software components. logic gates, or other integrated formats. Some aspects disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure.

The mechanisms of the disclosed subject matter are capable of being distributed as a program product in a variety of forms, and that an illustrative aspect of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include the following: a recordable type medium such as a floppy disk, a hard disk drive, a Compact Disc (CD), a Digital Video Disk (DVD), a digital tape, a computer memory, etc.; and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link (e.g., transmitter, receiver, transmission logic, reception logic, etc.).

The foregoing description of these aspects has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. These aspects were chosen and described in order to illustrate principles and practical application to thereby enable one of ordinary skill in the art to utilize the aspects and with modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

Various aspects of the subject matter described herein are set out in the following examples:

Example 1

A robotic surgical system, comprising: a control circuit configured to: detect a condition at an end effector during a closure phase; set command velocity of a motor coupled to a displacement member coupled to the end effector based on the detected condition at the end effector during the closure phase; fire the displacement member at the set command velocity; detect a condition at the end effector during a firing phase; and set command velocity of the motor based on the condition detected at the end effector during the firing phase.

Example 2

The robotic surgical system of Example 1, wherein the condition during the closure phase or the firing phase is tissue thickness and the control circuit is configured to detect a gap defined between an anvil and a staple cartridge portion of the end effector and adjust the command velocity based on the gap and the command velocity at the time the gap is detected.

Example 3

The robotic surgical system of any one of Example 1 through Example 2, wherein the condition during the closure phase is closure force applied to an anvil toward a staple cartridge and the control circuit is configured to detect a closure force defined as the force experienced by the anvil and the staple cartridge portion of the end effector closed on tissue located therebetween and adjust the command velocity based on the closure force and the command velocity at the time the force is detected.

Example 4

The robotic surgical system of any one of Example 1 through Example 3, wherein the condition during the firing phase is firing force to displace the displacement member and the control circuit is configured to detect a firing force to displace the displacement member and adjust the command velocity based on the firing force and the command velocity at the time the force is detected.

Example 5

The robotic surgical system of any one of Example 1 through Example 4, wherein the condition during the closure phase or the firing phase is electrical impedance of tissue located between an anvil and a cartridge in the end effector and the control circuit is configured to detect the electrical impedance of the tissue located between the anvil and the staple cartridge of the end effector and adjust the command velocity based on the electrical impedance and the command velocity at the time the impedance is detected.

Example 6

The robotic surgical system of any one of Example 1 through Example 5, wherein the condition during the closure phase or the firing phase is coverage of tissue in the end effector and the control circuit is configured to detect the coverage of tissue located between an anvil and a staple cartridge portion of the end effector and adjust the command velocity based on the coverage and the command velocity at the time the coverage is detected.

Example 7

The robotic surgical system of any one of Example 1 through Example 6, wherein the control circuit is configured to adjust the command velocity during the firing phase to adjust the velocity of the displacement member while firing.

Example 8

A robotic surgical system, comprising: a control circuit coupled to a motor and configured to set a command velocity of the motor during a closure phase or a firing phase, wherein the motor is configured to drive a displacement member at the command velocity, wherein the control circuit is configured to: detect a first condition at the end effector; detect a second condition at the end effector; set the command velocity of the motor based on the detected first and second conditions at the end effector; and fire the displacement member at the set command velocity.

Example 9

The robotic surgical system of any one of Example 8, wherein the first condition is tissue coverage in segmented sections of the end effector and the control circuit is configured to: receive tissue presence from a sensor located in a section in a section of the end effector; set the command velocity of the motor to a first velocity in sections of the end effector where there is no tissue; and set the command velocity of the motor to a second velocity in sections of the end effector where the tissue is located in the end effector, wherein the second velocity is less than the first velocity.

Example 10

The robotic surgical system of any one of Example 8 through Example 9, wherein the first condition is tissue thickness located at the end effector and the control circuit is configured to: receive tissue thickness from a gap sensor located in the end effector; and set the command velocity of the motor to a third velocity in sections of the end effector where the tissue thickness is greater than a threshold thickness, and wherein the third velocity is less than the second velocity.

Example 11

The robotic surgical system of any one of Example 8 through Example 10, wherein the first condition is closure force applied to the end effector and the control circuit is configured to: receive closure force from a sensor located in the end effector; and set the command velocity of the motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 12

The robotic surgical system of any one of Example 8 through Example 11, wherein the first condition is firing force to displace the displacement member and the control circuit is configured to: receive firing force from a sensor coupled to the output of the motor; and set the command velocity of the motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 13

The robotic surgical system of any one of Example 8 through Example 12, wherein the first condition is tissue impedance at the end effector and the control circuit is configured to: receive tissue impedance from a sensor located in the end effector; and set the command velocity of the motor to a third velocity in sections of the end effector where the impedance is greater than a threshold impedance, and wherein the third velocity is less than the second velocity.

Example 14

The robotic surgical system of any one of Example 8 through Example 13, wherein the second condition is tissue coverage in segmented sections of the end effector and the control circuit is configured to: receive tissue presence from a sensor located in a section in a section of the end effector; set the command velocity of the motor to a first velocity in sections of the end effector where there is no tissue; and set the command velocity of the motor to a second velocity in sections of the end effector where the tissue is located in the end effector, wherein the second velocity is less than the first velocity.

Example 15

The robotic surgical system of any one of Example 8 through Example 14, wherein the second condition is tissue thickness located at the end effector and the control circuit is configured to: receive tissue thickness from a gap sensor located in the end effector; and set the command velocity of the motor to a third velocity in sections of the end effector where the tissue thickness is greater than a threshold thickness, and wherein the third velocity is less than the second velocity.

Example 16

The robotic surgical system of any one of Example 8 through Example 15, wherein the second condition is closure force applied to the end effector and the control circuit is configured to: receive closure force from a sensor located in the end effector; and set the command velocity of the motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 17

The robotic surgical system of any one of Example 8 through Example 16, wherein the second condition is firing force to displace the displacement member and the control circuit is configured to: receive firing force from a sensor coupled to the output of the motor; and set the command velocity of the motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 18

The robotic surgical system of any one of Example 8 through Example 17, wherein the second condition is tissue impedance at the end effector and the control circuit is configured to: receive tissue impedance from a sensor located in the end effector; and set the command velocity of the motor to a third velocity in sections of the end effector where the impedance is greater than a threshold impedance, and wherein the third velocity is less than the second velocity.

Example 19

A robotic surgical system, comprising: a first motor to drive a displacement member coupled to a cutting member; a second motor to drive a closure tube coupled to an anvil portion of an end effector, wherein the closure tube is configured to close or open the anvil; and a control circuit coupled to the first and second motor, wherein control circuit is configured to set a command velocity of the first motor during a closure phase or a firing phase and set a command velocity of the second motor to apply a closure force to the closure tube coupled to the anvil, wherein the control circuit is configured to: detect a first condition at the end effector; detect a second condition at the end effector; set the first command velocity of the motor based on the detected first and second conditions at the end effector; and fire the displacement member at the first set command velocity.

Example 20

The robotic surgical system of Example 19, wherein the first condition is tissue coverage in segmented sections of the end effector and the control circuit is configured to: receive tissue presence from a sensor located in a section in a section of the end effector; set the command velocity of the first motor to a first velocity in sections of the end effector where there is no tissue; and set the command of the first motor to a second velocity in sections of the end effector where the tissue is located in the end effector; wherein the second velocity is less than the first velocity.

Example 21

The robotic surgical system of any one of Example 19 through Example 20, wherein the first condition is tissue thickness located at the end effector and the control circuit is configured to: receive tissue thickness from a gap sensor located in the end effector; and set the command velocity of the first motor to a third velocity in sections of the end effector where the tissue thickness is greater than a threshold thickness, and wherein the third velocity is less than the second velocity.

Example 22

The robotic surgical system of any one of Example 19 through Example 21, wherein the first condition is closure force applied to the end effector and the control circuit is configured to: receive closure force from a sensor coupled to an output shaft of the second motor; and set the command velocity of the first motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 23

The robotic surgical system of any one of Example 19 through Example 22, wherein the first condition is firing force to displace the displacement member and the control circuit is configured to: receive firing force from a sensor coupled to the output shaft of the first motor; and set the command velocity of the first motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 24

The robotic surgical system of any one of Example 19 through Example 23, wherein the first condition is tissue impedance at the end effector and the control circuit is configured to: receive tissue impedance from a sensor located in the end effector; and set the command velocity of the first motor to a third velocity in sections of the end effector where the impedance is greater than a threshold impedance, and wherein the third velocity is less than the second velocity.

Example 25

The robotic surgical system of any one of Example 19 through Example 24, wherein the first condition is tissue coverage in segmented sections of the end effector and the control circuit is configured to: receive tissue presence from a sensor located in a section in a section of the end effector; set the command velocity of the first motor to a first velocity in sections of the end effector where there is no tissue; and set the command of the first motor to a second velocity in sections of the end effector where the tissue is located in the end effector; wherein the second velocity is less than the first velocity.

Example 26

The robotic surgical system of any one of Example 19 through Example 25, wherein the first condition is tissue thickness located at the end effector and the control circuit is configured to: receive tissue thickness from a gap sensor located in the end effector; and set the command velocity of the first motor to a third velocity in sections of the end effector where the tissue thickness is greater than a threshold thickness, and wherein the third velocity is less than the second velocity.

Example 27

The robotic surgical system of any one of Example 19 through Example 26, wherein the first condition is closure force applied to the end effector and the control circuit is configured to: receive closure force from a sensor coupled to an output shaft of the second motor; and set the command velocity of the first motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 28

The robotic surgical system of any one of Example 19 through Example 27, wherein the first condition is firing force to displace the displacement member and the control circuit is configured to: receive firing force from a sensor coupled to the output shaft of the first motor; and set the command velocity of the first motor to a third velocity in sections of the end effector where the closure force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

Example 29

The robotic surgical system of any one of Example 19 through Example 28, wherein the first condition is tissue impedance at the end effector and the control circuit is configured to: receive tissue impedance from a sensor located in the end effector; and set the command velocity of the first motor to a third velocity in sections of the end effector where the impedance is greater than a threshold impedance, and wherein the third velocity is less than the second velocity.

The invention claimed is:

1. A robotic surgical system, comprising:

a shaft;

an end effector extending linearly from the shaft in an axial direction, wherein the end effector comprises a plurality of axially segmented sections;

a first motor to drive a displacement member coupled to a cutting member in the axial direction;

a second motor to drive a closure tube coupled to an anvil portion of the end effector, wherein the closure tube is configured to close or open the anvil portion; and

a control circuit coupled to the first and second motor, wherein control circuit is configured to set a command velocity of the first motor during a closure phase or a firing phase and set a command velocity of the second motor to apply a closure force to the closure tube coupled to the anvil portion, wherein the control circuit is configured to:

detect a first condition at a first segmented section of the plurality of axially segmented sections of the end effector;

detect a second condition at a second segmented section of the plurality of axially segmented sections of the end effector, wherein the second segmented section is axially offset from the first segmented section;

set the command velocity of the first motor to a first velocity based on the detected first condition; and

set the command velocity of the first motor to a second velocity based on the detected second condition, wherein the second velocity is different than the first velocity; and

wherein the control circuit is further configured to:

predict a current speed of the first motor based, at least in part, on a previously detected condition of the robotic surgical system;

determine an actual current speed of the first motor based, at least in part, on at least one of the detected first condition and the detected second condition;

compare the predicted current speed of the first motor to the actual current speed of the first motor; and

set the command velocity of the first motor to a third velocity based on the comparison.

2. The robotic surgical system of claim **1**, wherein the first condition is a closure force applied to the end effector and the control circuit is configured to:

receive the closure force applied to the end effector from a sensor coupled to an output shaft of the second motor; and

set the command velocity of the first motor to the third velocity in the first segmented section of the end effector where the closure force applied to the end effector is greater than a threshold force, and wherein the third velocity is less than the second velocity.

3. The robotic surgical system of claim **1**, wherein the first condition is a firing force to displace the displacement member and the control circuit is further configured to set the command velocity of the first motor to the third velocity in the first segmented section of the end effector where the firing force is greater than a threshold force, and wherein the third velocity is less than the second velocity.

4. The robotic surgical system of claim **1**, further comprising a first sensor positioned within the first segmented section and a second sensor positioned within the second segmented section.

5. The robotic surgical system of claim **4**, wherein the first condition is no tissue presence, wherein the second condition is tissue presence, and wherein the second velocity is less than the first velocity.

6. The robotic surgical system of claim **4**, wherein the first condition is a tissue thickness located at the first segmented section of the end effector, wherein the first sensor is a gap sensor, and the control circuit is configured to set the command velocity of the first motor to the third velocity in the first segmented section of the end effector where the tissue thickness is greater than a threshold thickness, and wherein the third velocity is less than the second velocity.

7. The robotic surgical system of claim **4**, wherein the first condition is a tissue impedance at the first segmented section of the end effector and the control circuit is configured to set the command velocity of the first motor to the third velocity in the first segmented section of the end effector where the tissue impedance is greater than a threshold impedance, and wherein the third velocity is less than the second velocity.

8. A robotic surgical system, comprising:

a shaft;

an end effector extending linearly from the shaft, wherein the end effector comprises linearly offset segmented sections;

a first motor to drive a displacement member coupled to a cutting member through the segmented sections;

a second motor to drive a closure tube coupled to an anvil portion of the end effector, wherein the closure tube is configured to close or open the anvil portion; and

a control circuit coupled to the first and second motor, wherein control circuit is configured to set a command velocity of the first motor during a closure phase or a firing phase and set a command velocity of the second motor to apply a closure force to the closure tube coupled to the anvil portion, wherein the control circuit is configured to:

detect a first condition at a first segmented section of the segmented sections of the end effector;

detect a second condition at a second segmented section of the segmented sections of the end effector, wherein the second segmented section is linearly offset from the first segmented section;

set the command velocity of the first motor to a first velocity based on the detected first condition; and

set the command velocity of the first motor to a second velocity based on the detected second condition, wherein the second velocity is different than the first velocity; and

wherein the control circuit is further configured to:

predict a current speed of the first motor based, at least in part, on a previously detected condition of the robotic surgical system;

determine an actual current speed of the first motor based, at least in part, on at least one of the detected first condition and the detected second condition;

compare the predicted current speed of the first motor to the actual current speed of the first motor; and

set the command velocity of the first motor to a third velocity based on the comparison.

9. The robotic surgical system of claim **8**, further comprising a first sensor positioned within the first segmented section and a second sensor positioned within the second segmented section.

10. A robotic surgical system, comprising:

a shaft;

an end effector extending linearly from the shaft in an axial direction, wherein the end effector comprises a plurality of axially segmented sections;

a first motor to drive a displacement member coupled to a cutting member in the axial direction;

a second motor to drive a closure tube coupled to an anvil portion of an the end effector, wherein the closure tube is configured to close or open the anvil portion;

a control circuit coupled to the first and second motor, wherein control circuit is configured to set a command velocity of the first motor during a firing phase, wherein the control circuit is configured to:

detect a first condition at a first segmented section of the plurality of axially segmented sections of the end effector;

detect a second condition at a second segmented section of the plurality of axially segmented sections of the end effector, wherein the second segmented section is axially offset from the first segmented section;

alter a firing stroke by setting the command velocity of the first motor to a first velocity based on the detected first condition; and

further alter the firing stroke by setting the command velocity of the first motor to a second velocity based on the detected second condition; and

a memory coupled to the control circuit, wherein the memory is configured to store a profile of the robotic surgical system, and wherein the control circuit is further configured to:

characterize the robotic surgical system based, at least in part, on the detected first condition and the detected second condition;

compare the characterization of the robotic surgical system to the stored profile of the robotic surgical system; and

alter an initial command velocity of the first motor based, at least in part, on the comparison of characterization of the robotic surgical system to the stored profile of the robotic surgical system.

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